LCWS2023

My Personal Highlights

Karsten Buesser

LCWS2023

26.05.2023

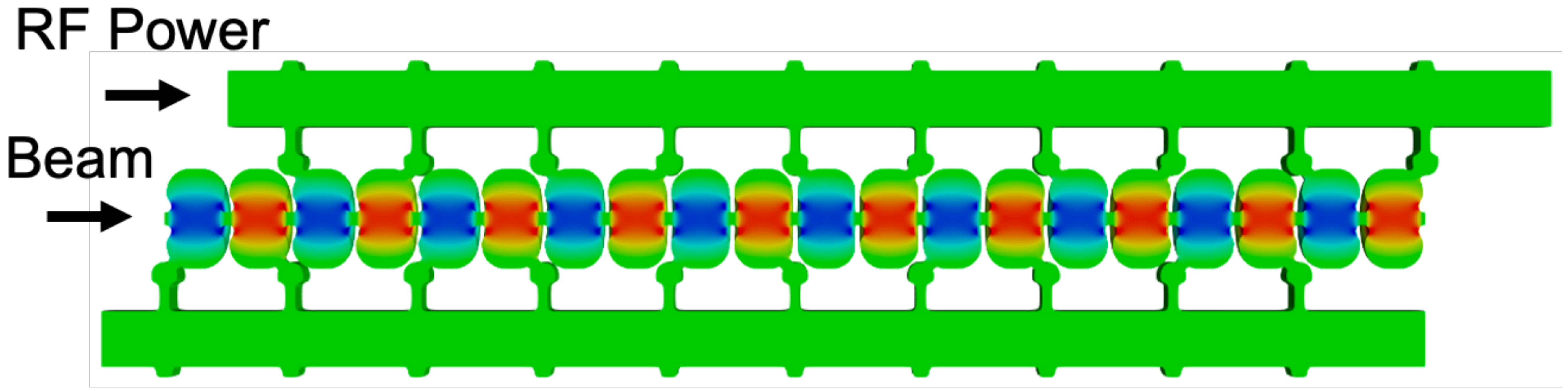
C^3 Cool Copper Collider

C^3 is a new linac **normal conducting technology**

C. Vernieri

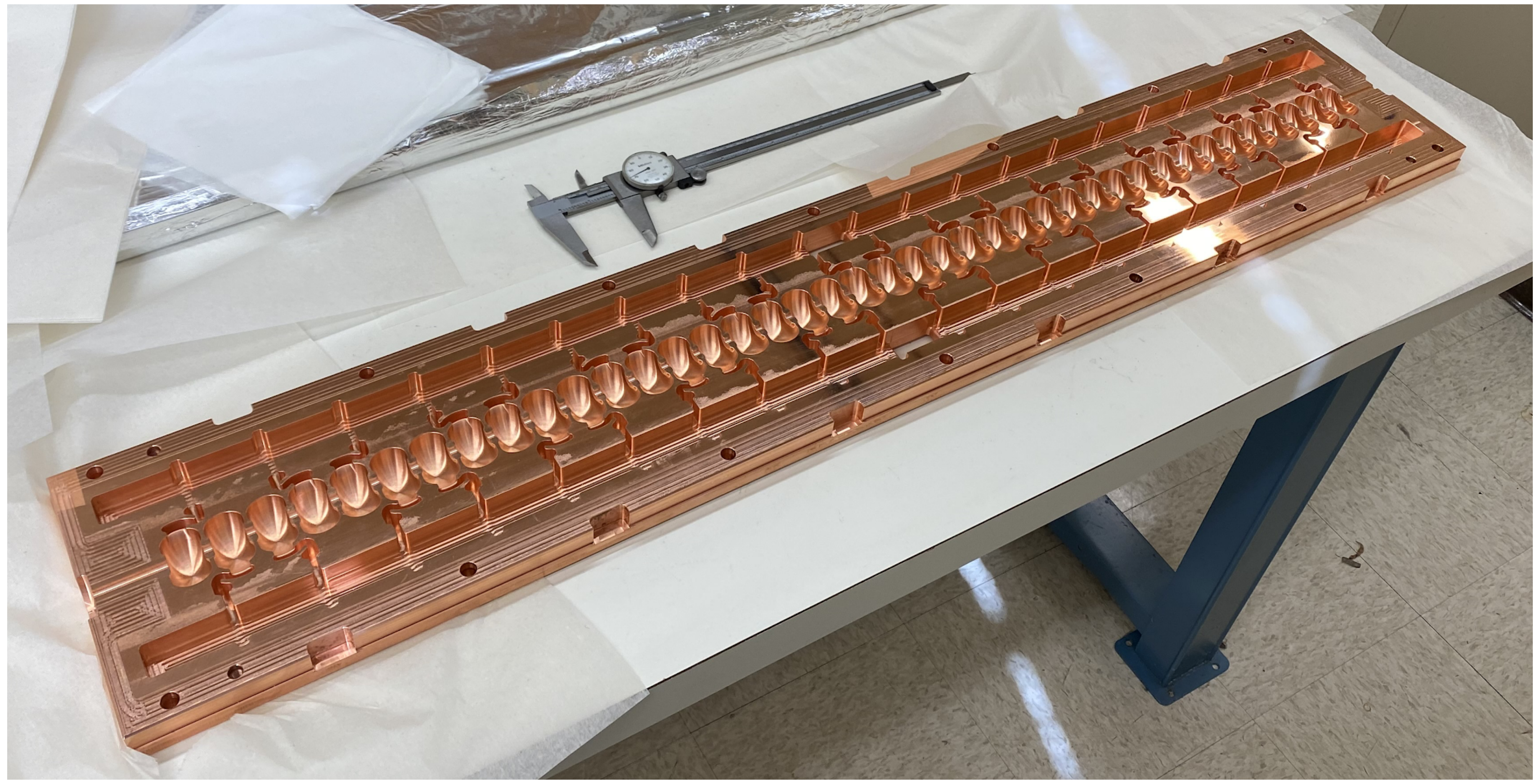
Optimize each cavity for maximum efficiency and lower surface fields

- Relatively small iris such that RF fundamental does not propagate through irises.
- RF power coupled to each cell – no on-axis coupling - required modern super-computing
  - Distributed power to each cavity from a common RF manifold
  - Mechanical realization by modern CNC milling



Electric field magnitude for equal power from RF manifold

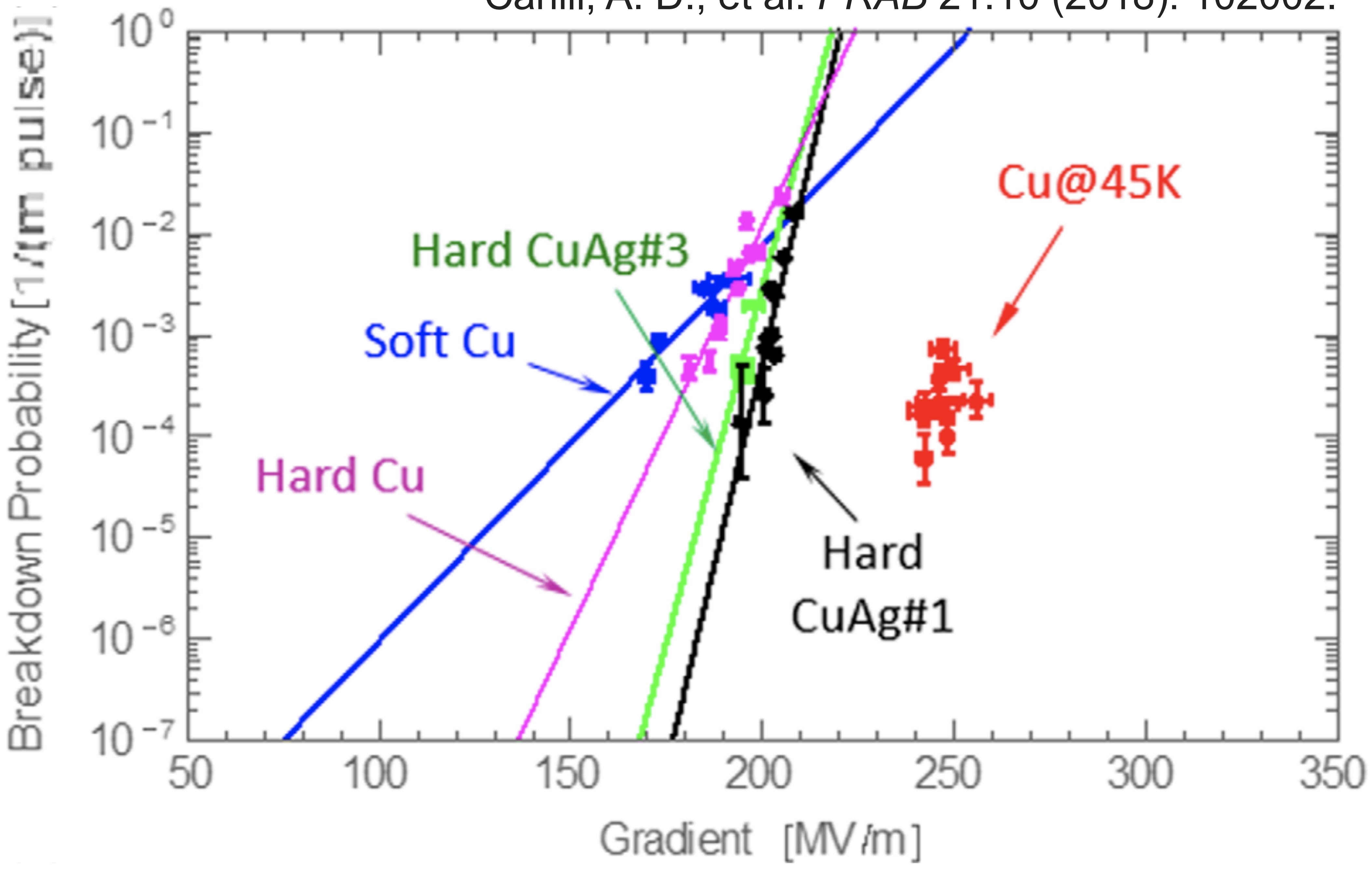
First C^3 structure at SLAC

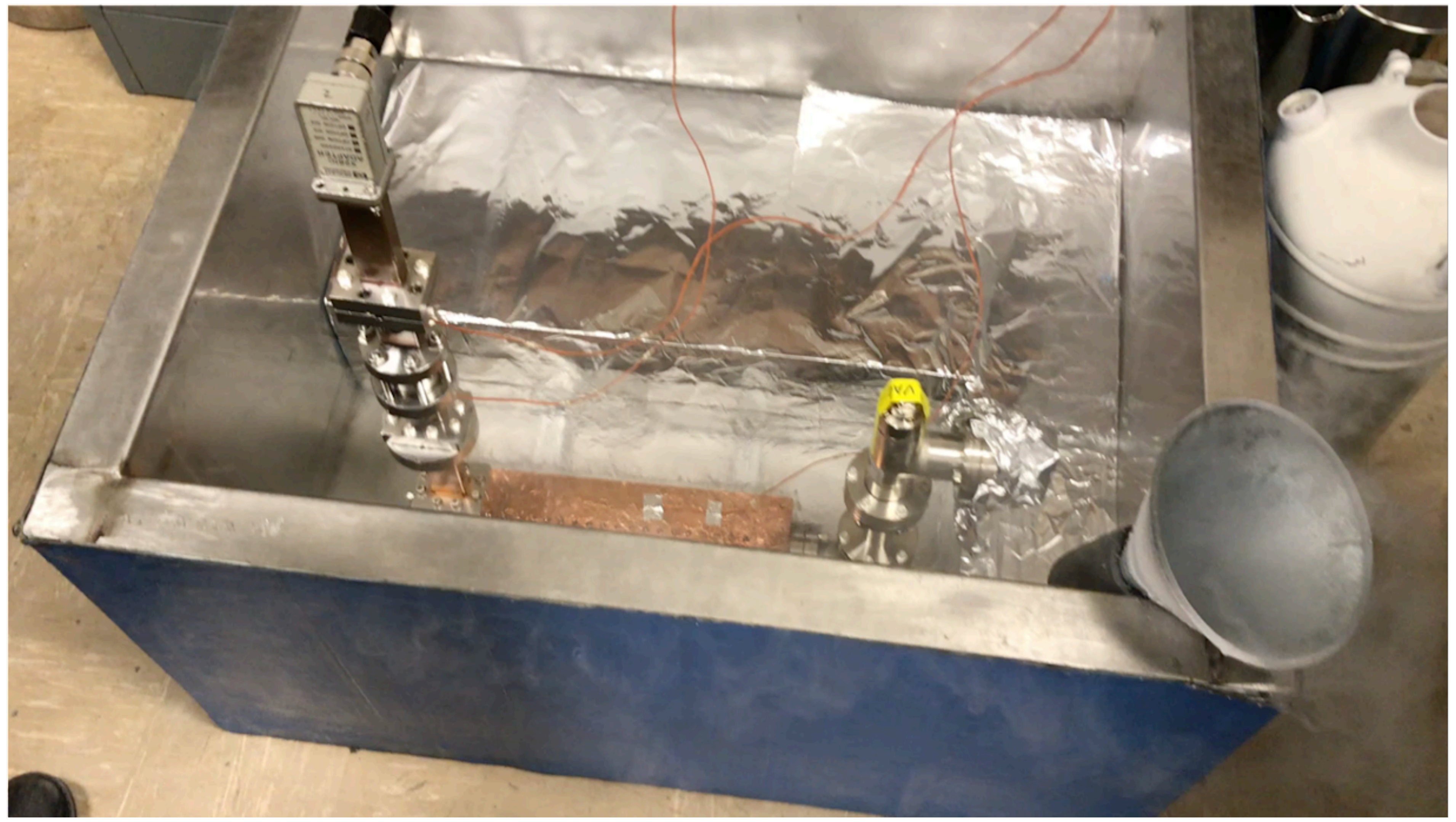


ArXiv:2210.17022

Why cool?

Cahill, A. D., et al. *PRAB* 21.10 (2018): 102002.





Nasr, et al. *PRAB* 24.9 (2021): 093201.

- Cryogenic temperature elevates performance in gradient
    - Increased material strength for gradient
    - Increase electrical conductivity reduces pulsed heating in the material
- Operation at 77 K with liquid nitrogen is simple and practical

C. Vernieri

Accelerator Complex

8 km footprint for 250/550 GeV CoM $\Longrightarrow$ 70/120 MeV/m

- 7 km footprint at 155 MeV/m for 550 GeV CoM – present Fermilab site

Large portions of accelerator complex compatible between LC technologies

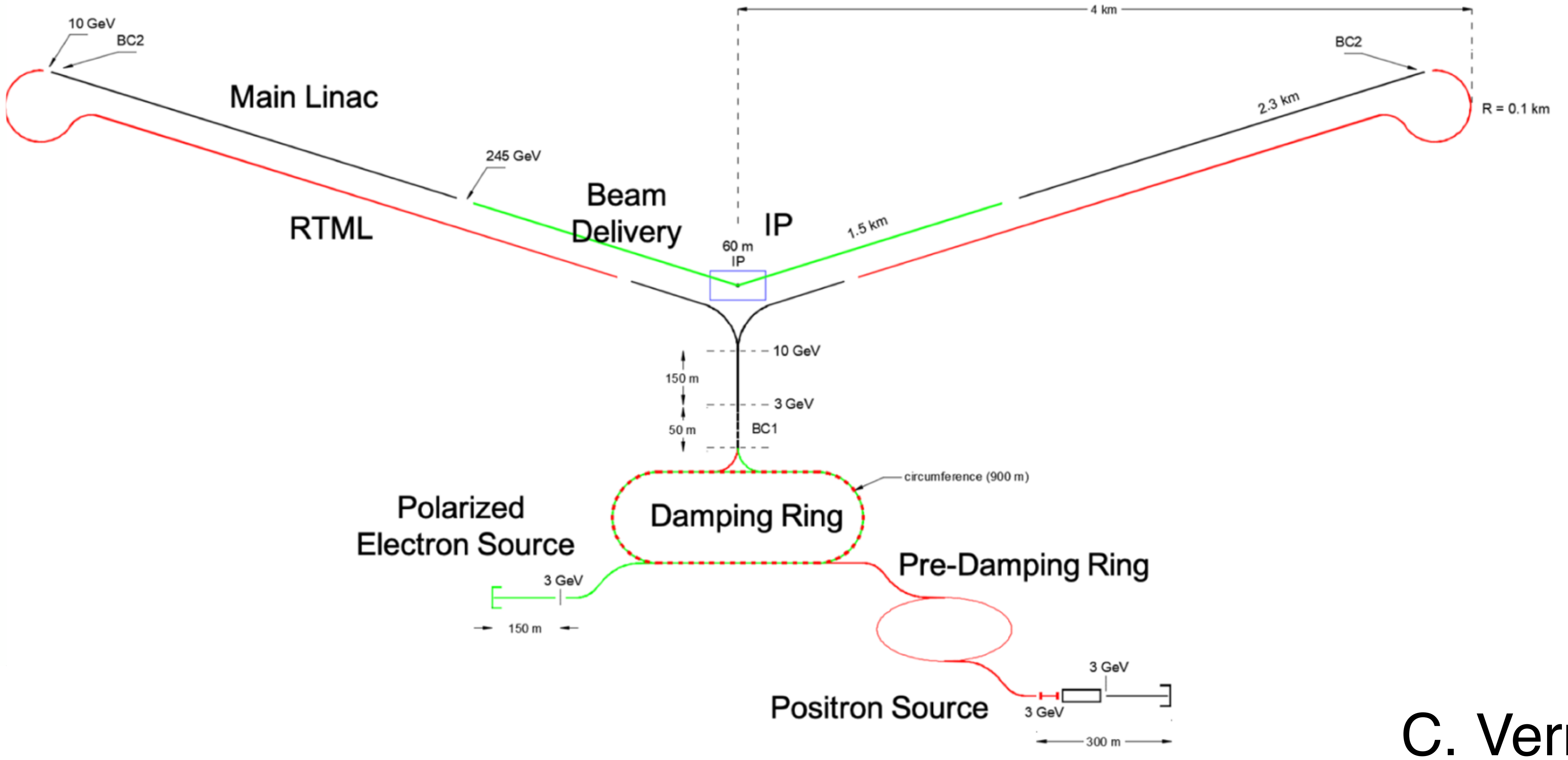
- Beam delivery / IP modified from ILC (1.5 km for 550 GeV CoM)
- Damping rings and injectors to be optimized with CLIC as baseline

Fits onto Fermilab site

C³ Parameters

Collider	C^3	C^3
CM Energy [GeV]	250	550
Luminosity [x10^{34}]	1.3	2.4
Gradient [MeV/m]	70	120
Effective Gradient [MeV/m]	63	108
Length [km]	8	8
Num. Bunches per Train	133	75
Train Rep. Rate [Hz]	120	120
Bunch Spacing [ns]	5.26	3.5
Bunch Charge [nC]	1	1
Crossing Angle [rad]	0.014	0.014
Site Power [MW]	~150	~175
Design Maturity	pre-CDR	pre-CDR

C³ - 8 km Footprint for 250/550 GeV



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C. Vernieri

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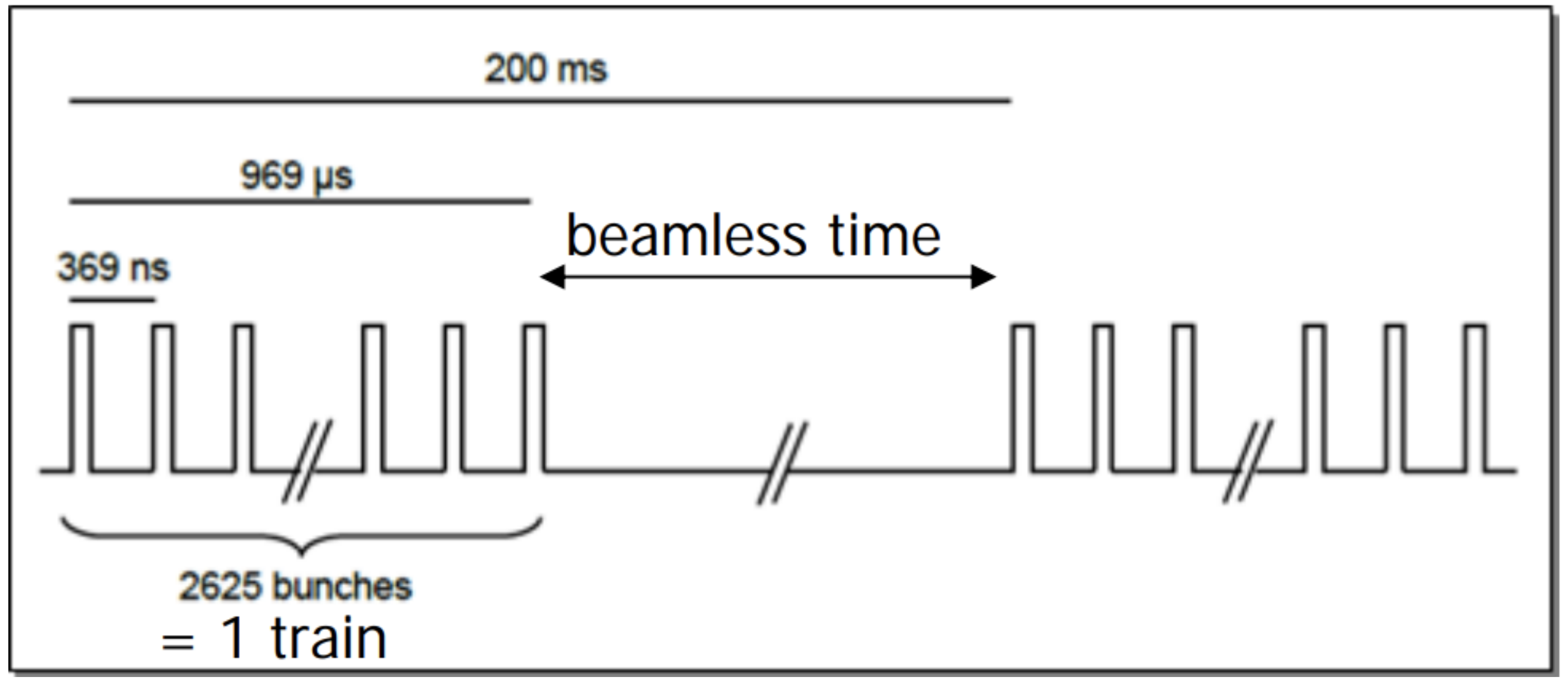
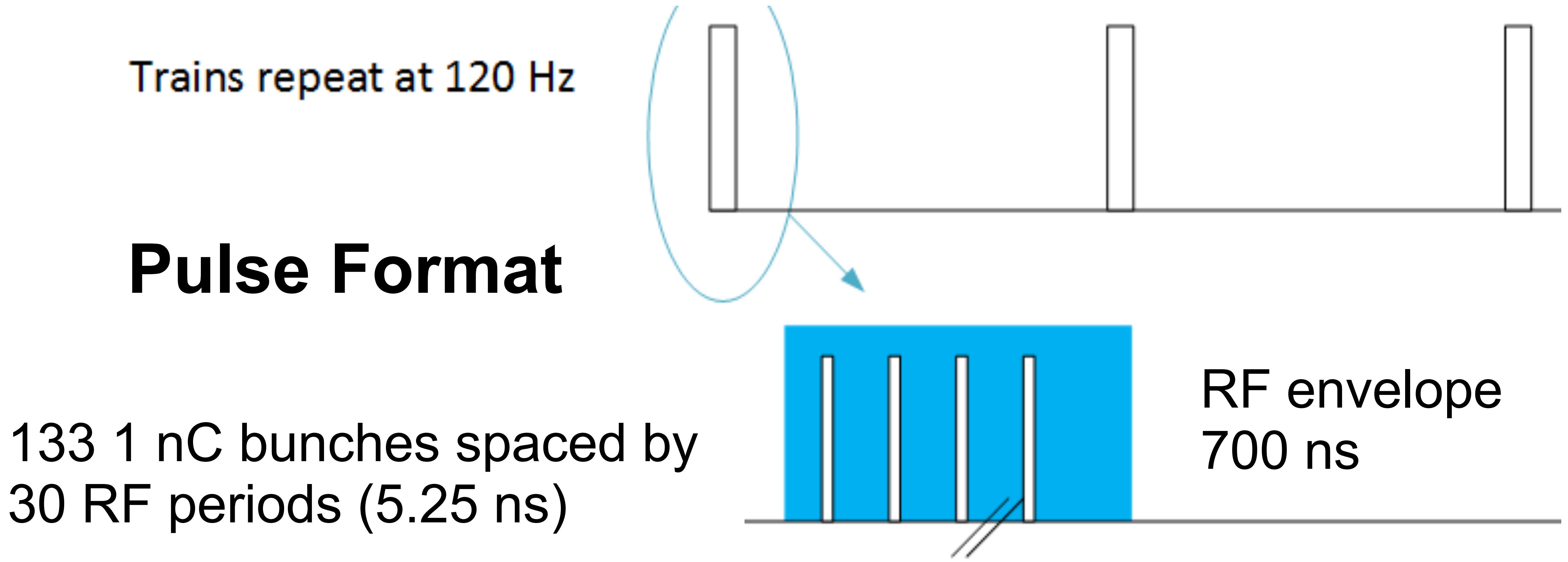
Beam Format and Detector Design Requirements

ILC timing structure



1 ms long bunch trains at 5 Hz
308ns spacing

C^3 timing structure



ILC/C^3 timing structure: Fraction of a percent duty cycle

- **Power pulsing possible**, significantly reduce heat load
  - Factor of 100 power saving for FE analog power
- Tracking detectors **don't need active cooling**
  - Significantly reduction for the material budget

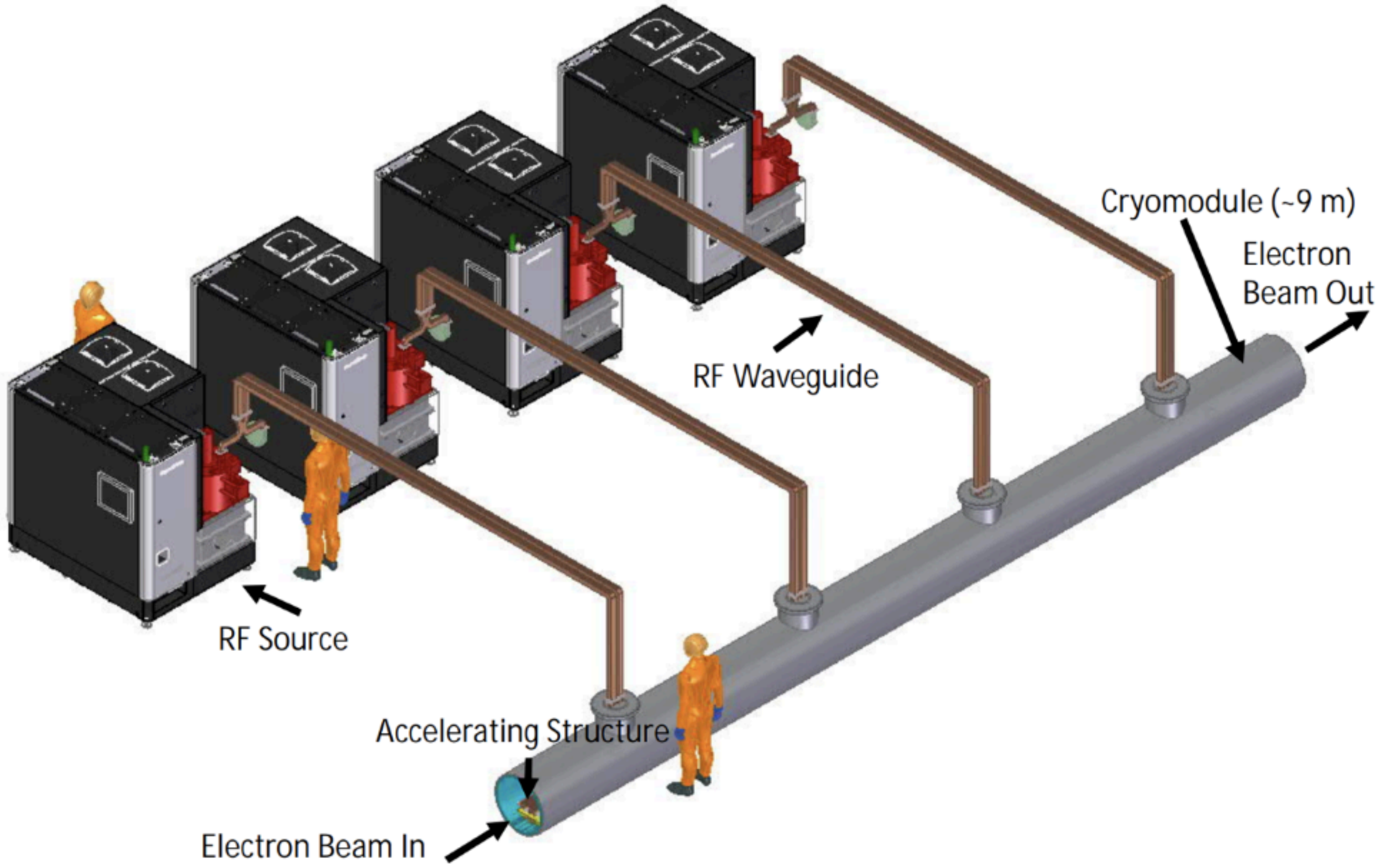
C^3 time structure is compatible with ILC-like detector overall design and ongoing optimizations.

Tunnel Layout for Main Linac 250/550 GeV CoM

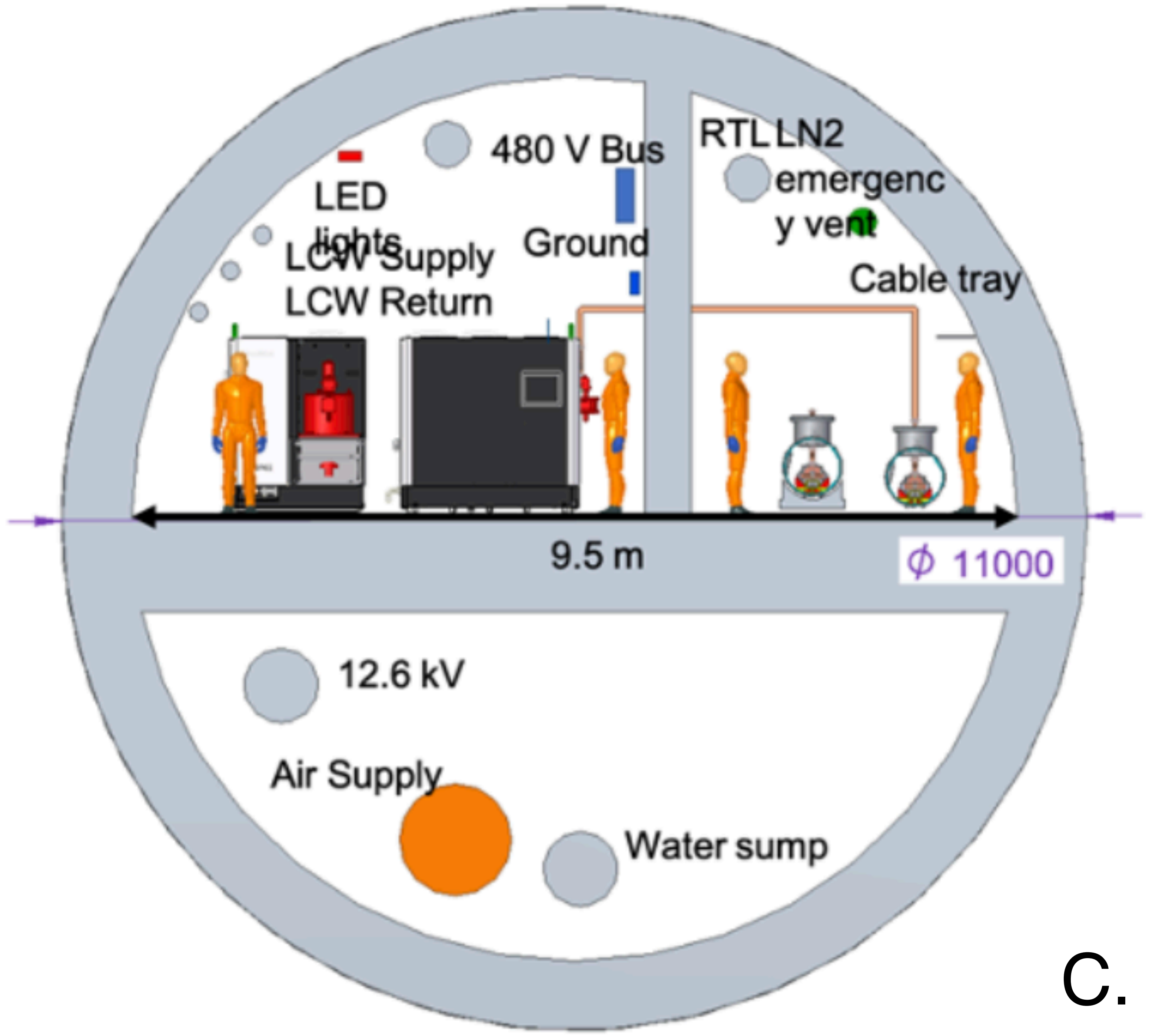
First study looked at 9.5 m inner diameter in order to match ILC costing model

- Must minimize diameter to reduce cost and construction time
- Surface site (cut/cover) provides interesting alternative – concerns with length of site for future upgrade

Cryomodule Unit - 9 m
(630 MeV/1 GeV)



Usable Tunnel Width - 9.5 m
(Same tunnel width as ILC)



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Technical Timeline for 250/550 GeV CoM

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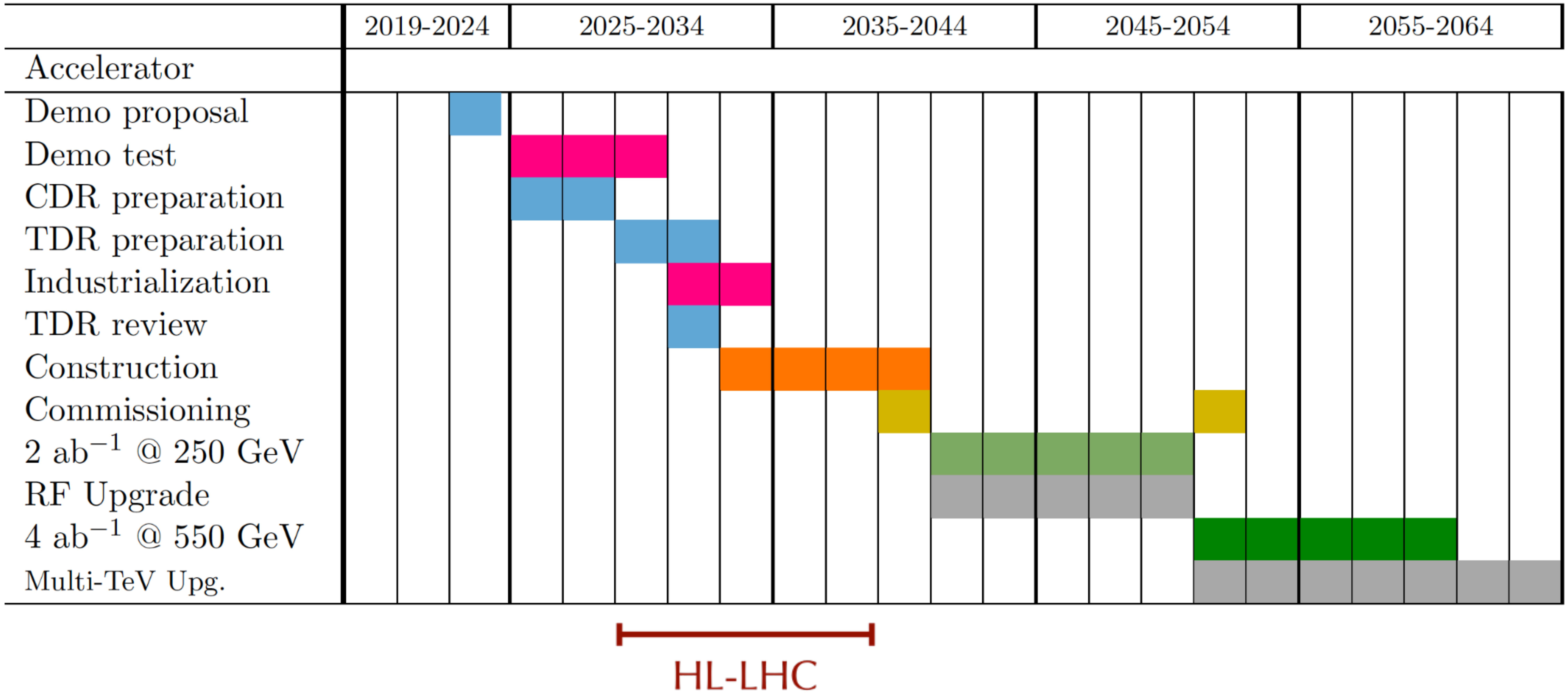
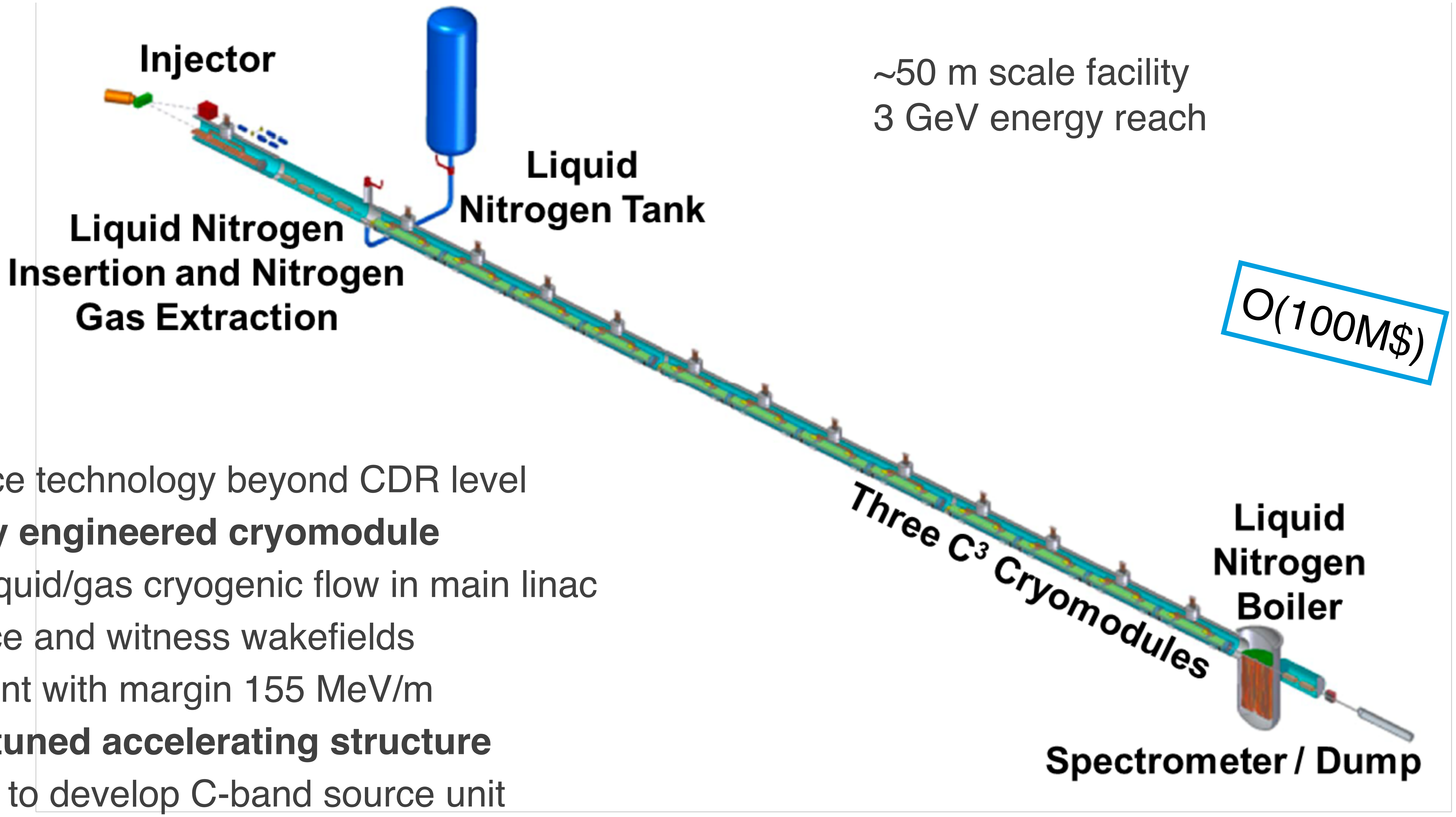
Energy upgrade in parallel to operation with installation of additional RF power sources



The Complete C³ Demonstrator

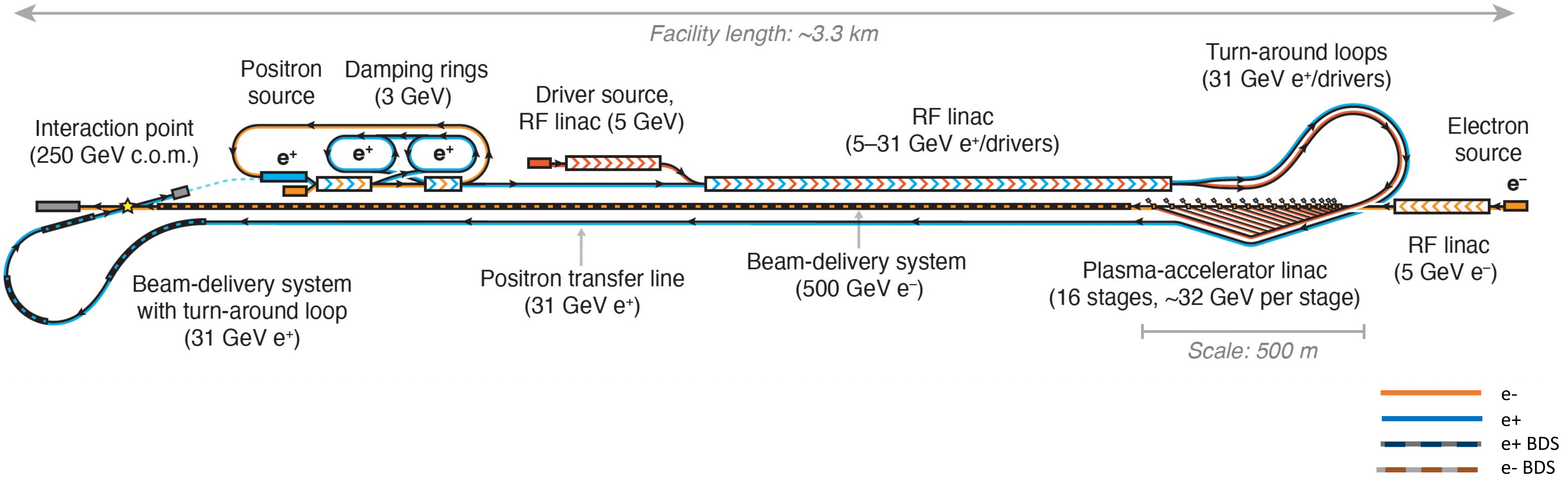


R&D needed to advance technology beyond CDR level

- **Demonstrate fully engineered cryomodule**
- Demonstrate full liquid/gas cryogenic flow in main linac
- Multi-Bunch: Induce and witness wakefields
- Operational gradient with margin 155 MeV/m
- **Fully damped-detuned accelerating structure**
- Work with industry to develop C-band source unit optimized for installation with main linac

HALHF

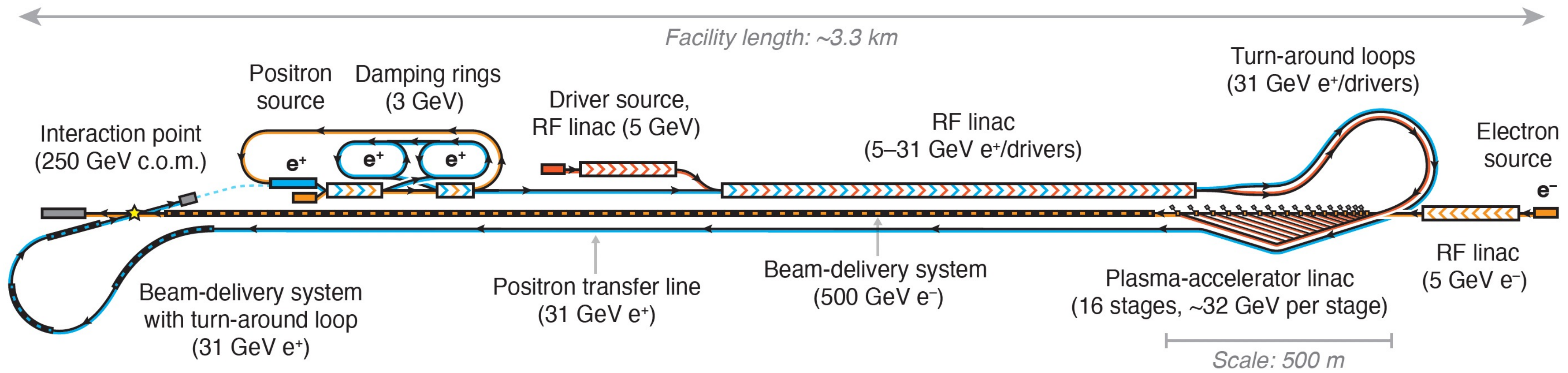
HALHF Layout



- Overall facility length ~ 3.3 km – which will fit on ~ any of the major (or even ex-major) pp labs. (NB. There is a service tunnel a la ILC (not shown))

B. Foster, LCWS, 5/23

Cost Estimate



- Scale from existing costed projects wherever possible – mostly ILC – very rough – not better than 25% accurate.

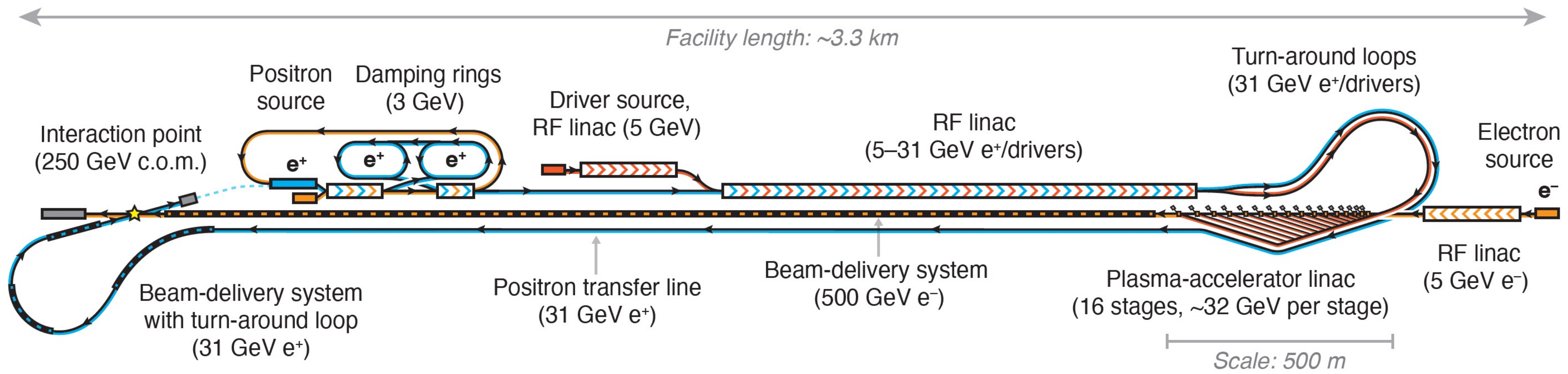
Subsystem	Original cost (MILCU)	Comment	Scaling factor	HALHF cost (MILCU)	Fraction
Particle sources, damping rings	430	CLIC cost [69], halved for e^+ damping rings only[a]	0.5	215	14%
RF linac with klystrons	548	CLIC cost, as RF power is similar	1	548	35%
PWFA linac	477	ILC cost [47], scaled by length and multiplied by 6[b]	0.1	48	3%
Transfer lines	477	ILC cost, scaled to the ∼4.6 km required[c]	0.15	72	5%
Electron BDS	91	ILC cost, also at 500 GeV	1	91	6%
Positron BDS	91	ILC cost, scaled by length[d]	0.25	23	1%
Beam dumps	67	ILC cost (similar beam power) + drive-beam dumps[e]	1	80	5%
Civil engineering	2,055	ILC cost, scaled to the ∼10 km of tunnel required	0.21	476	31%
			Total	1,553	100%

[a] Swiss deflator from 2018 → 2012 is approximately 1. Conversion uses Jan 1st 2012 CHF to $ exchange rate of 0.978.
[b] Cost of PWFA linac similar to ILC standard instrumented beam lines plus short plasma cells & gas systems plus kickers/chicanes. The factor 6 is a rough estimate of extra complexity involved.
[c] The positron transfer line, which is the full length of the electron BDS, dominates; this plus two turn-arounds, the electron transport to the positron source plus small additional beam lines are costed.
[d] The HALHF length is scaled by $\sqrt{E}$ and the cost assumed to scale with this
[e] Length of excavation and beam line taken from European XFEL dump.

Total project cost (US accounting): O(3 G$) same as for EIC!

B. Foster, LCWS, 5/23

Summary & Conclusion



- HALHF benefits from maximal asymmetry.
- Even if e^+ acceleration not a problem, HALHF could still be best way forward – but requires > a decade of significant R&D.
- Conventional design work needed: DR with high bunch charge; heavily loaded linac; BDS…
- PWFA R&D: higher accelerated charge (x ~10), higher repetition rate (x ~1000), plasma-cell power dissipation (x ~1000), beam jitter reduction (x ~10-100).
- BUT – if R&D successful, HALHF would be the first e^+e^- Higgs Factory proposal that costs ~ same as a “national” project.

B. Foster, LCWS, 5/23

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ILC in Japan

Let's go back
2 years ago

2. Prelab was linked to approval of ILC

Message from MEXT (March 2021)

Message given by the MEXT Minister @ the Diet

- The ILC project needs to resolve its various challenges including its **international cost sharing** and **technical feasibility**, as well as to **obtain broad internal and external cooperation** not for its pre-laboratory but for the ILC project itself.

- Under the current situation that the perspective of broad internal and external cooperation for the ILC project itself as well as its pre-laboratory is not promised, it is difficult to obtain the people's understanding in Japan for investing the pre-laboratory. It is necessary to obtain the clear perspectives on financial contributions to the ILC project itself from the US and European countries in prior considering the pre-laboratory."

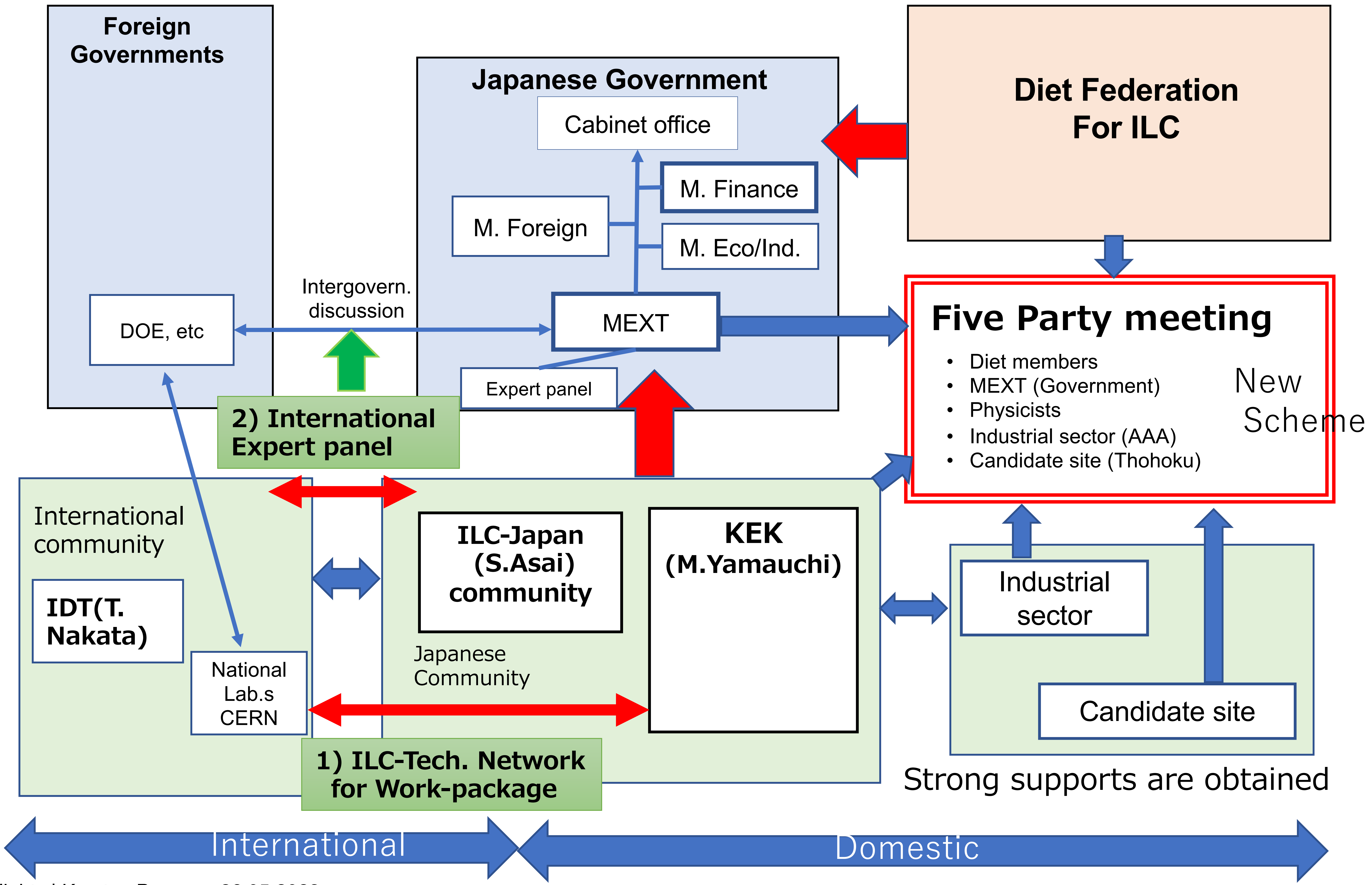
Three keys to move ILC forward given by MEXT/JG:
1. Technical feasibility
2. International cost sharing
3. Broad consensus

S. Asai

As shown in Tatsuya's talk

We have to overcome the gap between Governments (Global vs International)

Promotion scheme of ILC / relation of Stakeholder



S. Asai

4. ILC Promotions in World-Wide with IDT

ILC-Technology Network to implement the most urgent work-packages in advance.

The budget in Japan in JFY2023 ~ 9.7 hundred Million Yen: Increases by Factor2
Shin Michizono-san has shown the detailed R&D plan in the morning session.

- The ITN is a network of the accelerator laboratories:
  KEK, CERN, US National Labs. and Asian Labs···
  (It will be launched by agreements between KEK and a partner laboratory which define the deliverables and obligations)

Purposes

- Make international cooperation tighter / dependable @ Govern. level
  (See Tastuya's IDT talk)
- Improve the reliability and completeness of ILC technology
- Potential for application of ILC Technologies

S. Asai

7. Timeline / Step-by-Step ILC promotion

This Timeline is considered,
Discussed in IDT/ICFA/Diet Federation.
not Government approved.

IDT view on the ILC project timeline
-success oriented and asuming no major incident-

Technology Network Phase | Preparatory Phase | Construction Phase ~10 years for the construction and commissioning

2021 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035

1st 2nd 3rd

1st stage Prepare ILCTN
International expert panel makes global script.

Condition

- Budget is ready
- Various National Labs join ILCTN

S. Asai

2nd Stage ILC TN develops TC-WP

Community cultivates environment for international discussion (both @ scientist community and government level)

Japan takes role / initiative in ILCTN (we are asking to JG)

Condition

- FCC-ee FS final report
- recognize ILC as the most realistic, cost-friendly, carbon-friendly project
- Understand of Governments/Communities ILC is global project
- Better International situation(Pandemic, global economy, tension)

3rd Stage Governments discuss cost sharing/responsibility of ILC (as Global project)

Condition

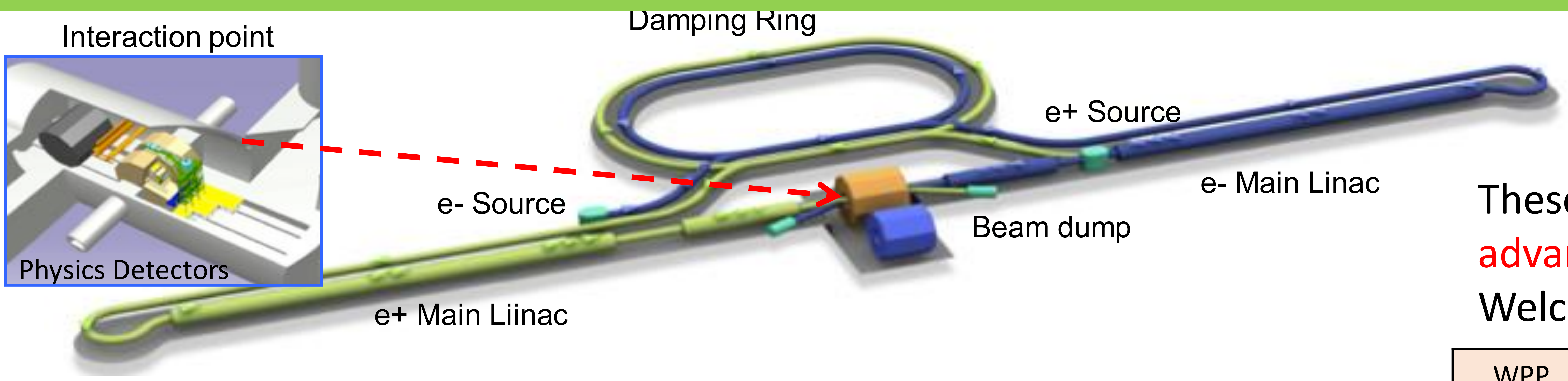
- Fix final cost including civil engineering
- Cost sharing / responsibilities are agreed @ Governments

Start construction.

S. Asai

WP-Primes at ILC Technology Network

ilc international development team



These WPs can be applied to various advanced accelerators.
Welcome to join!

- Creating particles — ***Sources***
  - polarized elections / positrons
- High quality beams — ***Damping ring***
  - Low emittance beams
    - Small beam size (small beam spread)
    - Parallel beam (small momentum spread)
- Acceleration — ***Main linac***
  - superconducting radio frequency (SRF)
- Getting them collided — ***Final focus***
  - nano-meter beams
- Go to ***Beam dumps***

SRF

e-, e+ Sources

Nano-Beam

WPP	1	Cavity production
WPP	2	CM design
WPP	3	Crab cavity
WPP	4	E- source
WPP	6	Undulator target
WPP	7	Undulator focusing
WPP	8	E-driven target
WPP	9	E-driven focusing
WPP	10	E-driven capture
WPP	11	Target replacement
WPP	12	DR System design
WPP	14	DR Injection/extraction
WPP	15	Final focus
WPP	16	Final doublet
WPP	17	Main dump

LCWS2023 (Shin MICHIZONO)

S. Michizono

Sustainability

CO2 Intensity of Electricity in the Future

What will the CO2 impact of electricity be for the next generation of colliders?

- CO_2 intensity of electricity will go down
- Regenerative energies will rise

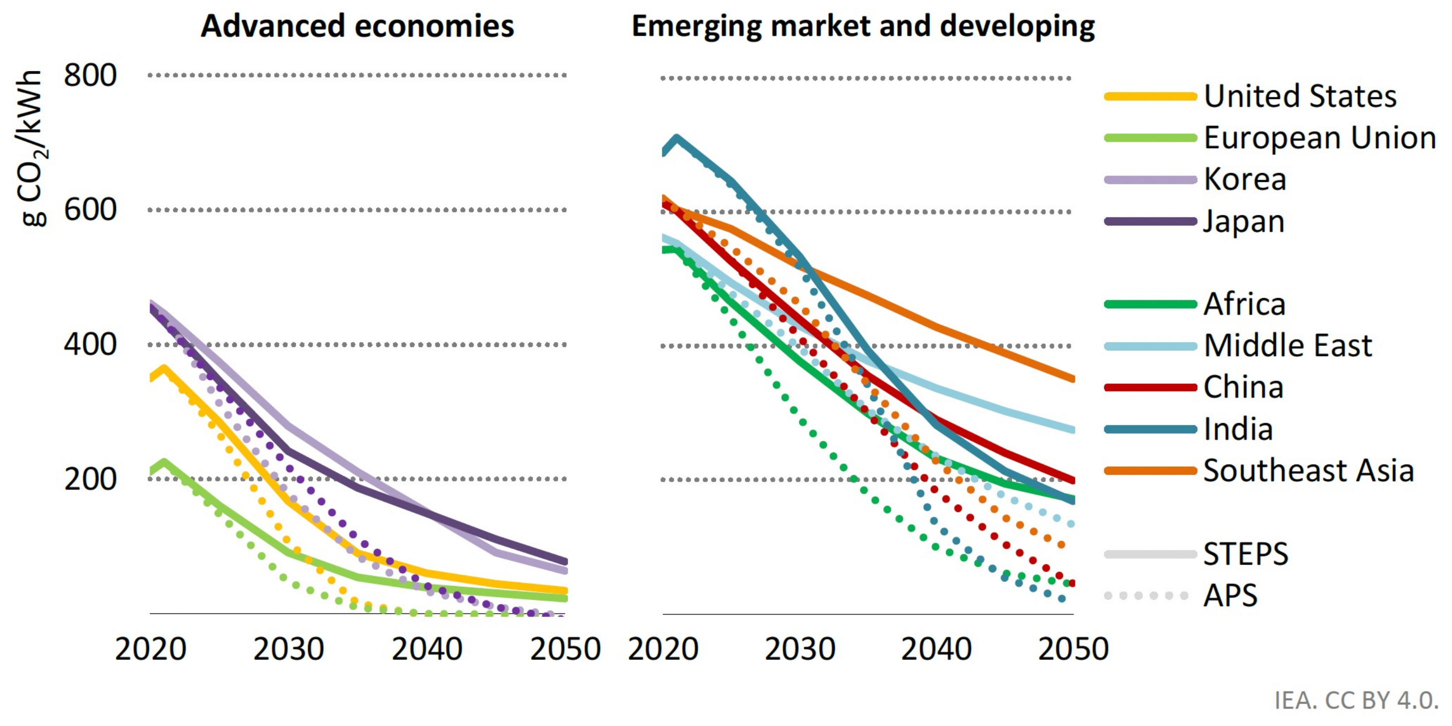
But

- Not enough – big gap between stated policies to announced pledges, even bigger to net zero -> we are not on a path to net zero!
- The energy transition will be a huge effort:
  - Energy storage
  - Energy transport (grid)
- Carbon intensity heavily site dependent
- Electricity will remain expensive

Therefore

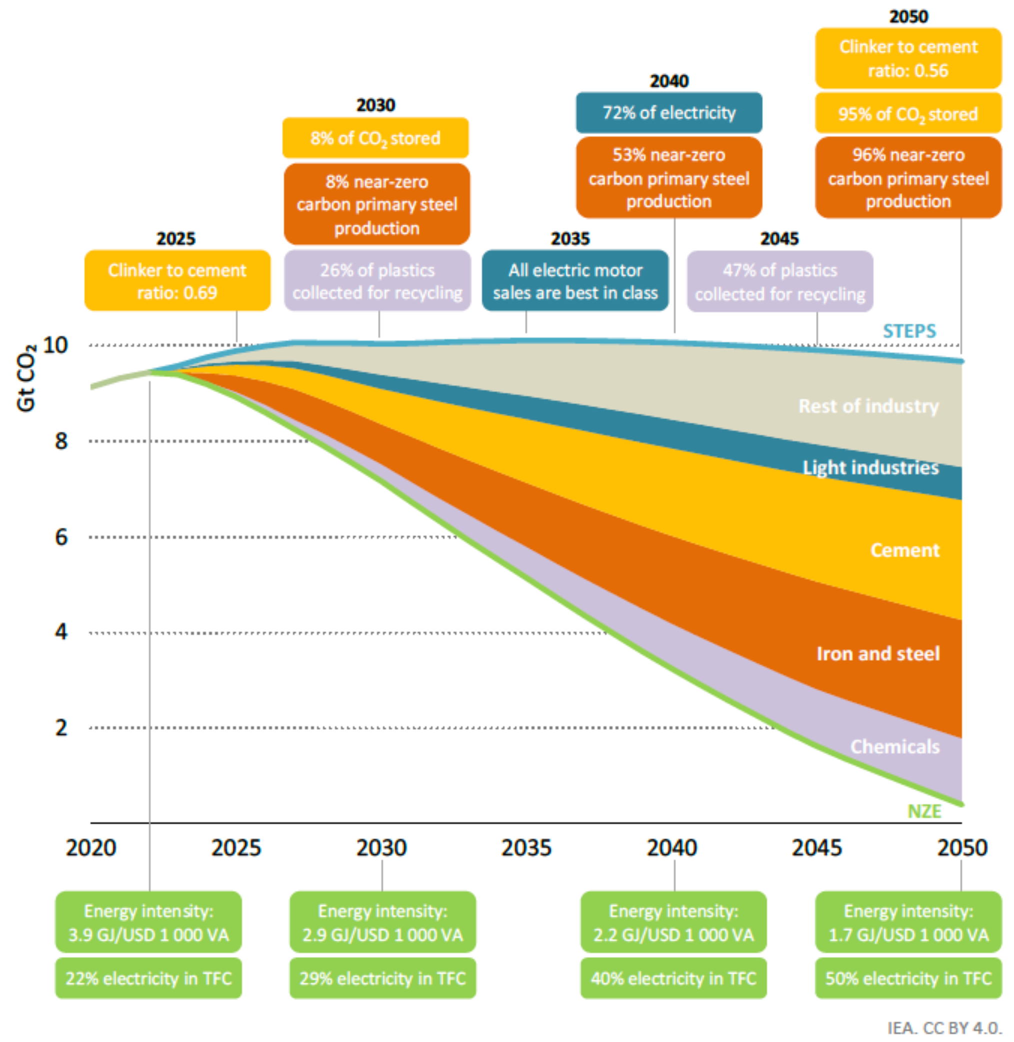
- Power consumption remains important
- Consensus needed which values to use
- How to treat site dependencies? (All projects would look best in Norway…)

Figure 6.14 ▷ Average CO_2 intensity of electricity generation for selected regions by scenario, 2020-2050



CO_2 intensity of electricity generation varies widely today, but all regions see a decline in future years and many have declared net zero emissions ambitions by around 2050

Figure 3.11 ▷ Emissions reductions and key milestones in the industry sector in the NZE Scenario relative to the STEPS, 2020-2050



Gap between Stated Policies and Net Zero Scenarios

B. List

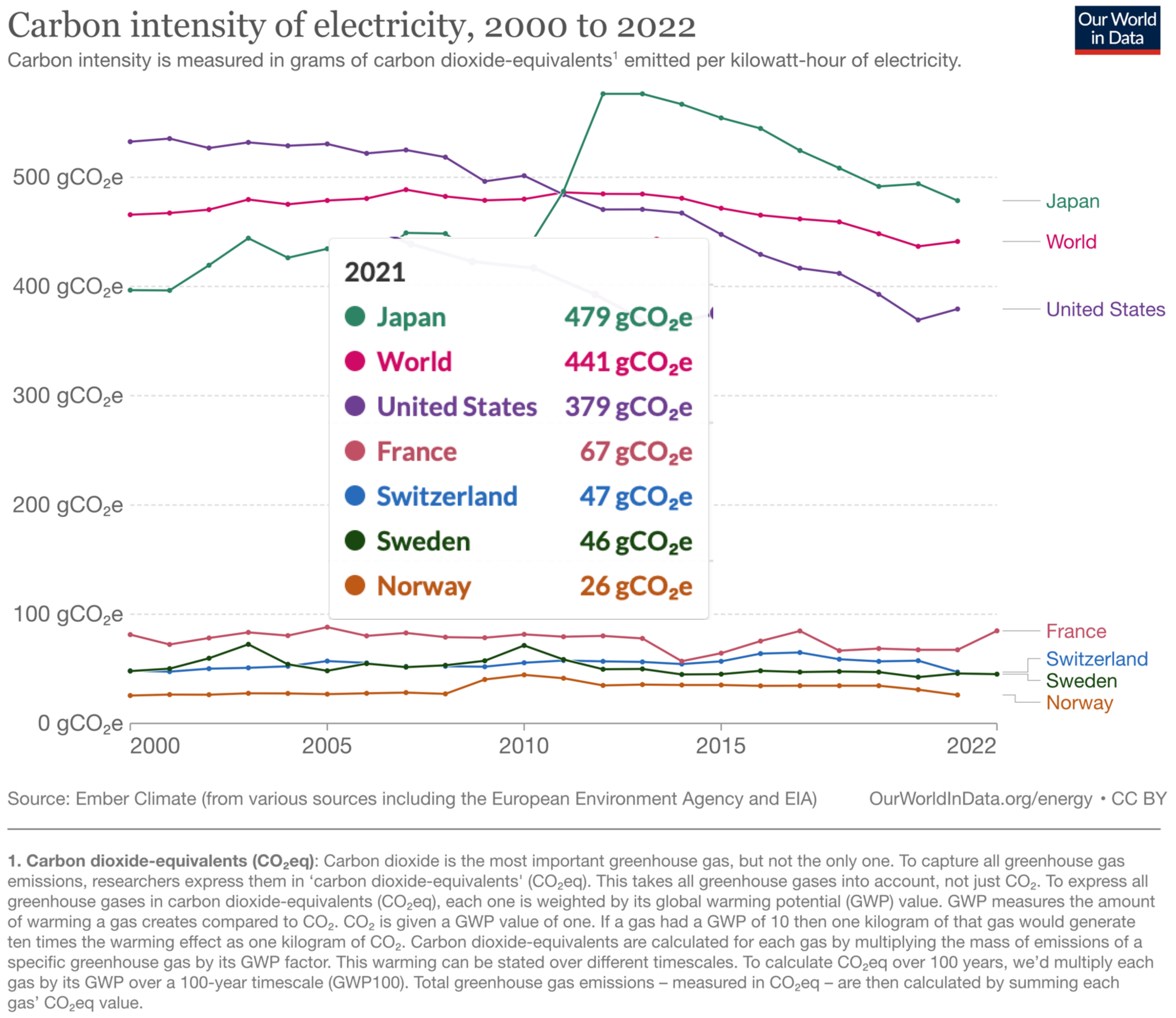
Carbon Intensity of Electricity and Accelerator: CLIC

- Example: For CERN / France in 2040 (summer) assume (*)
  - 50% nuclear power @ 5g CO2/kWh
  - 50% regenerative @ 20g CO2/kWh
  - -> 12.5g CO2/kWh
- 1TWh -> 12.5ktons CO2
- ILC / CLIC: ~0.6TWh / a

Compare to accelerator:

- Tunnel: ~6.5 ktons / km
- Accelerator: 2.5 ktons / km
- Services etc: ???

Very roughly, for CLIC:
1km of main linac = 1 year of operation



https://ourworldindata.org/grapher/carbon-intensity-electricity CC-BY

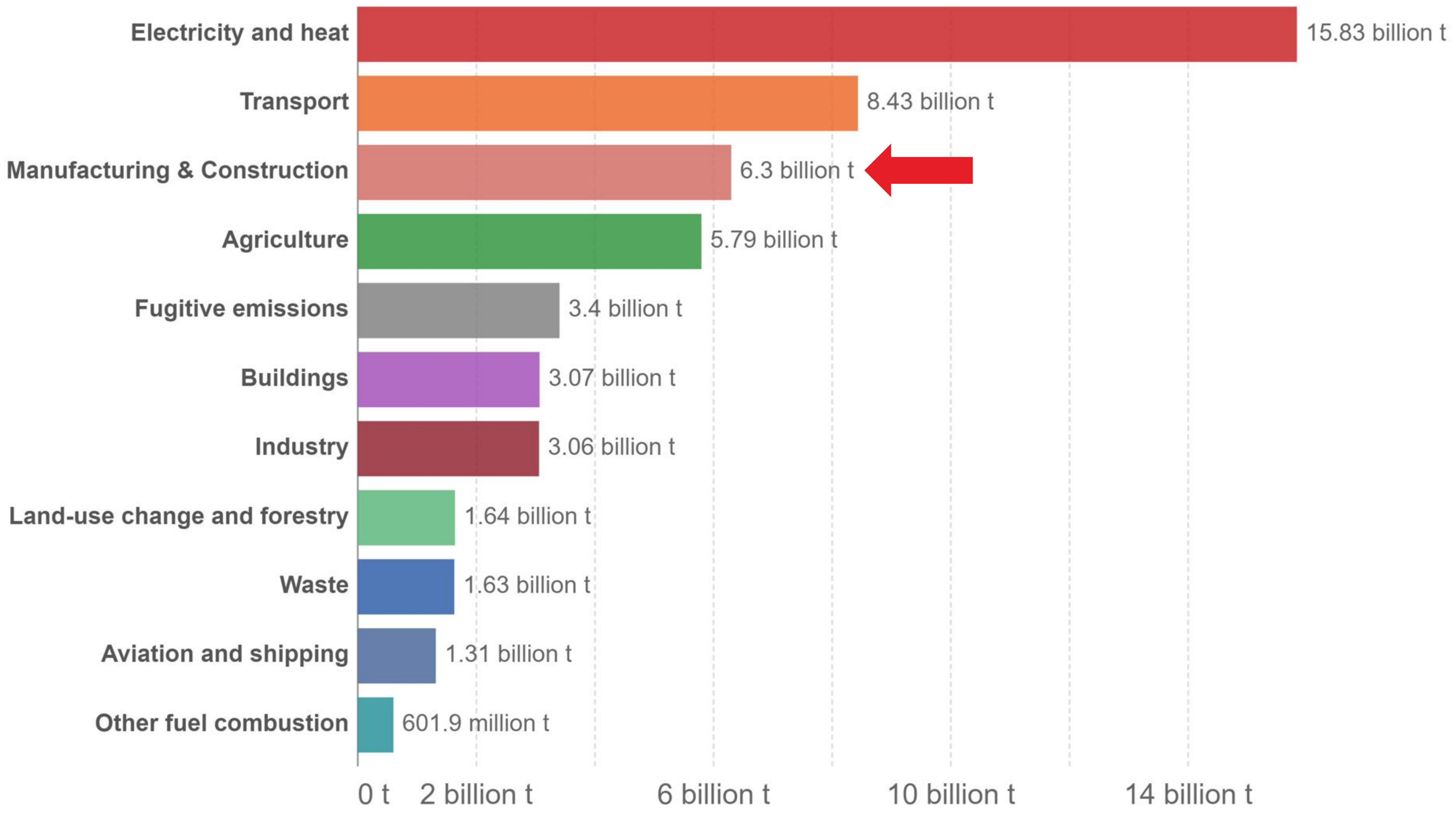
(*) https://app.electricitymaps.com/zone/FR
based on https://unece.org/info/publications/pub/371403

B. List

Global GHG Emissions

(tCO_2e)

ARUP



Our World in Data based on Climate Analysis Indicators Tool (CAIT) 2019 (Adapted)

ARUP

System boundaries

S. Evans

Before use stage [A0-A5]
- A0 Preliminary studies
- Materials:
  - **A1** Raw material supply
  - **A2** Transport
  - **A3** Manufacture
- Transport & construction activities:
  - **A4** Transport to works site
  - **A5** Construction process

Use stage [B1-B8]
- B1 Use
- B2 Maintenance
- B3 Repair
- B4 Replacement
- B5 Refurbishment
- B6 Operational Energy Use
- B7 Operational Water Use
- B8 User utilisation of infrastructure

End of life stage [C1-C4]
- C1 Deconstruction/ Demolition
- C2 Transport for Disposal
- C3 Waste Processing for recovery
- C4 Disposal

Benefits and Loads beyond the system boundary [D]

Reuse
Recycling

Benefits and loads of additional infrastructure functions

BS EN 17472:2022

Linear Collider Options

ARUP

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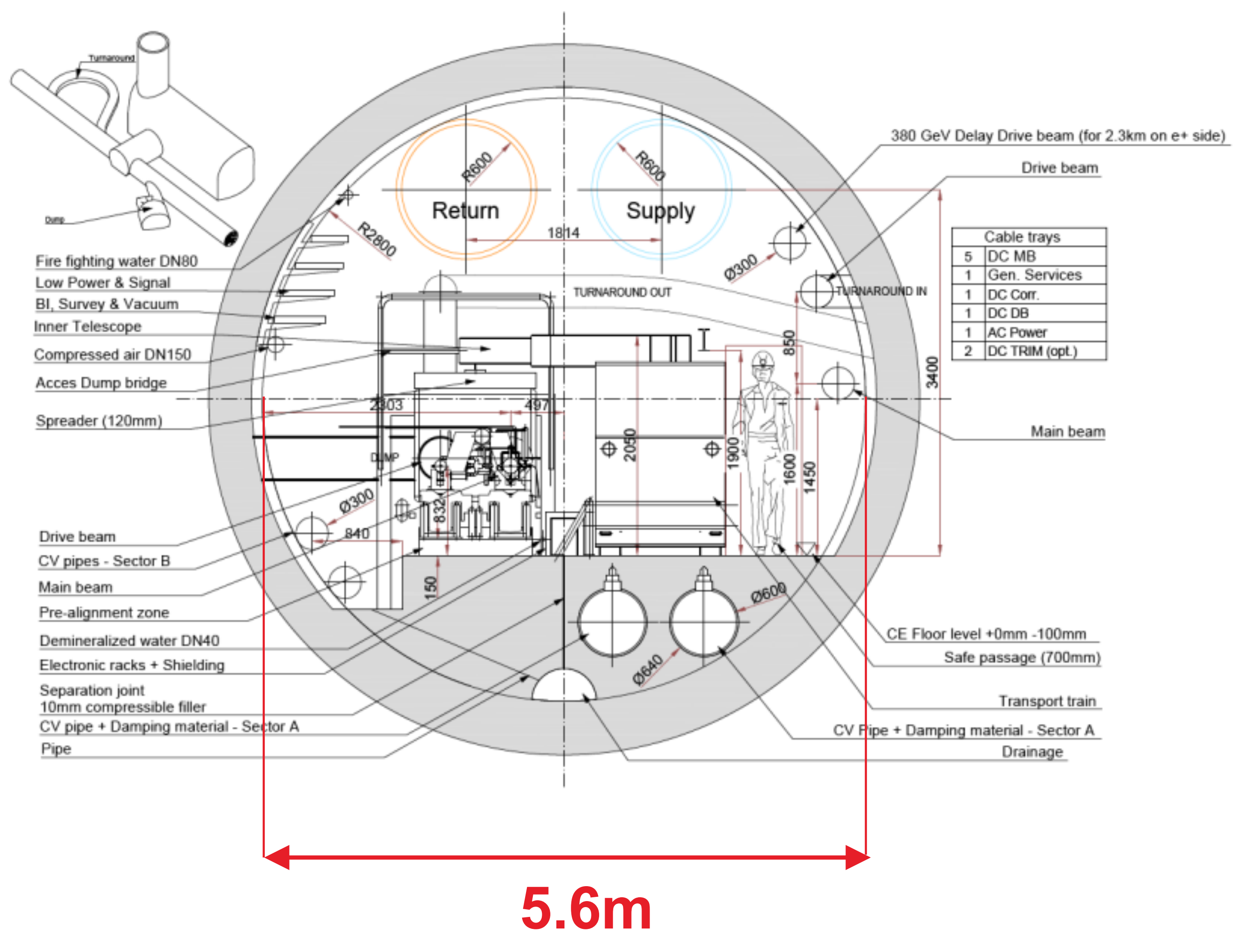
1. CLIC Drive Beam

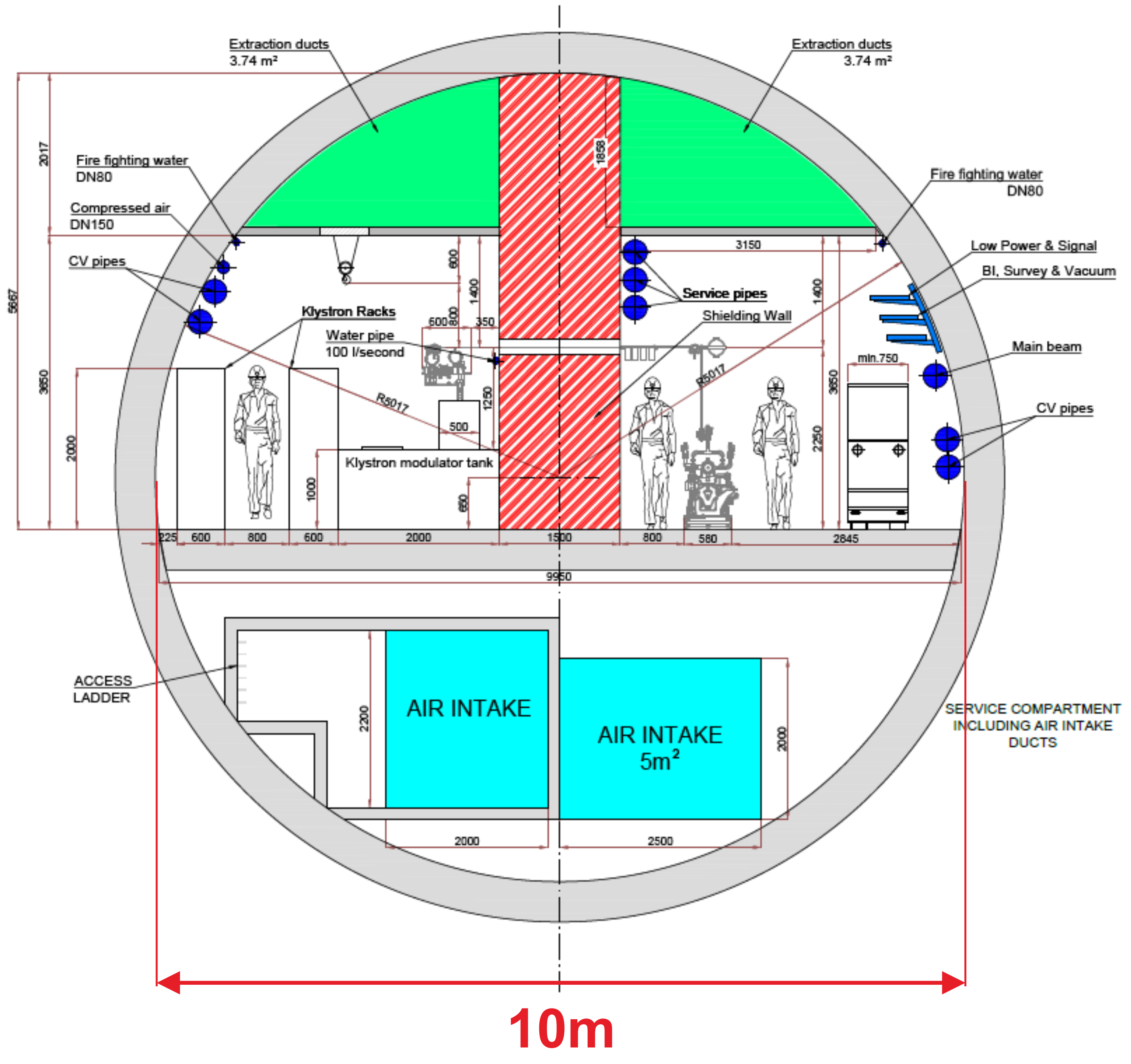
5.6m internal dia. Geneva.
(380GeV, 1.5TeV, 3TeV)



Reference: CLIC Drive Beam tunnel cross section, 2018

2. CLIC Klystron

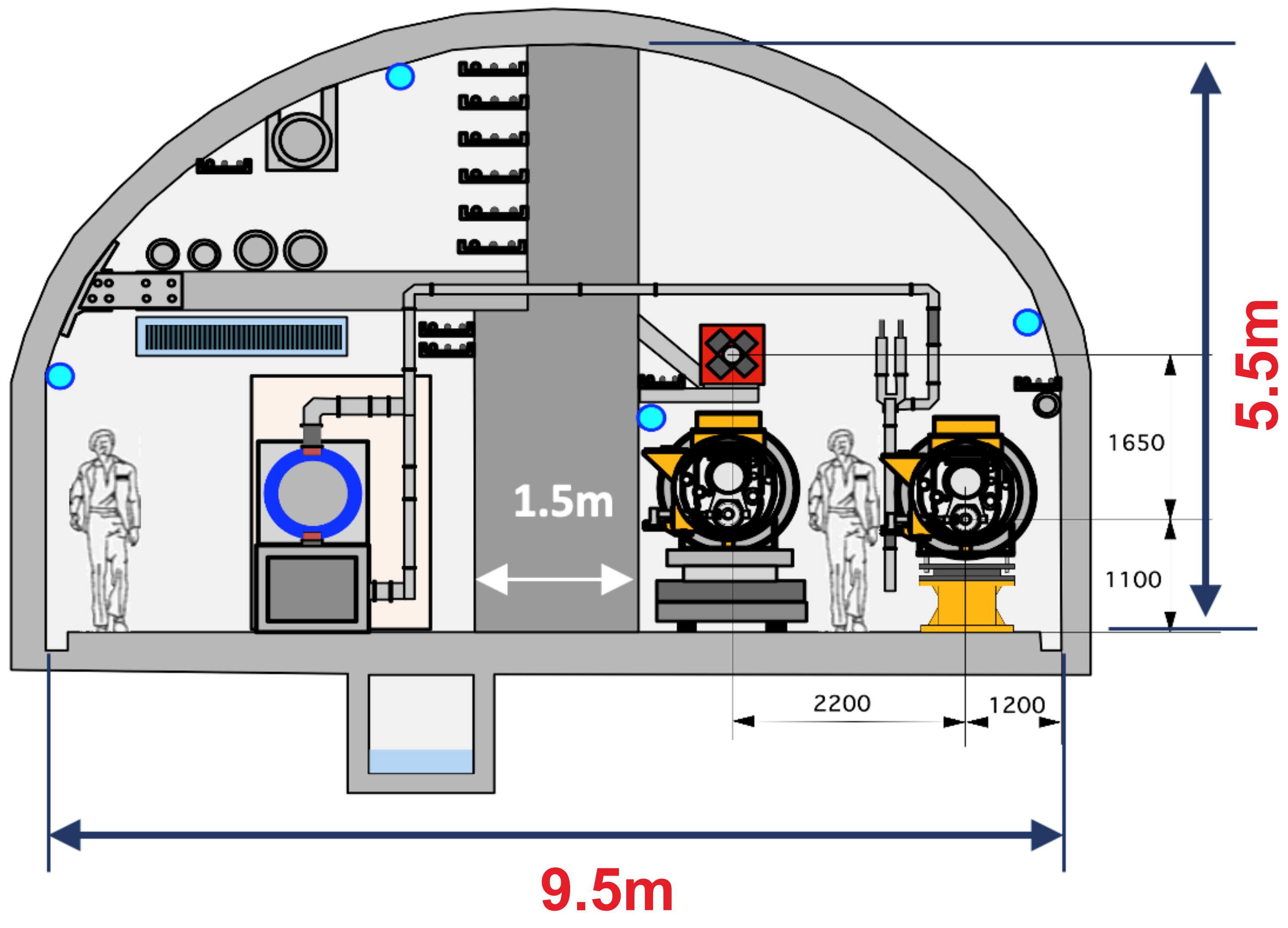
10m internal dia. Geneva.
(380GeV)



Reference: CLIC Klystron tunnel cross section, 2018

3. ILC

Arched 9.5m span. Japan.
(250GeV)



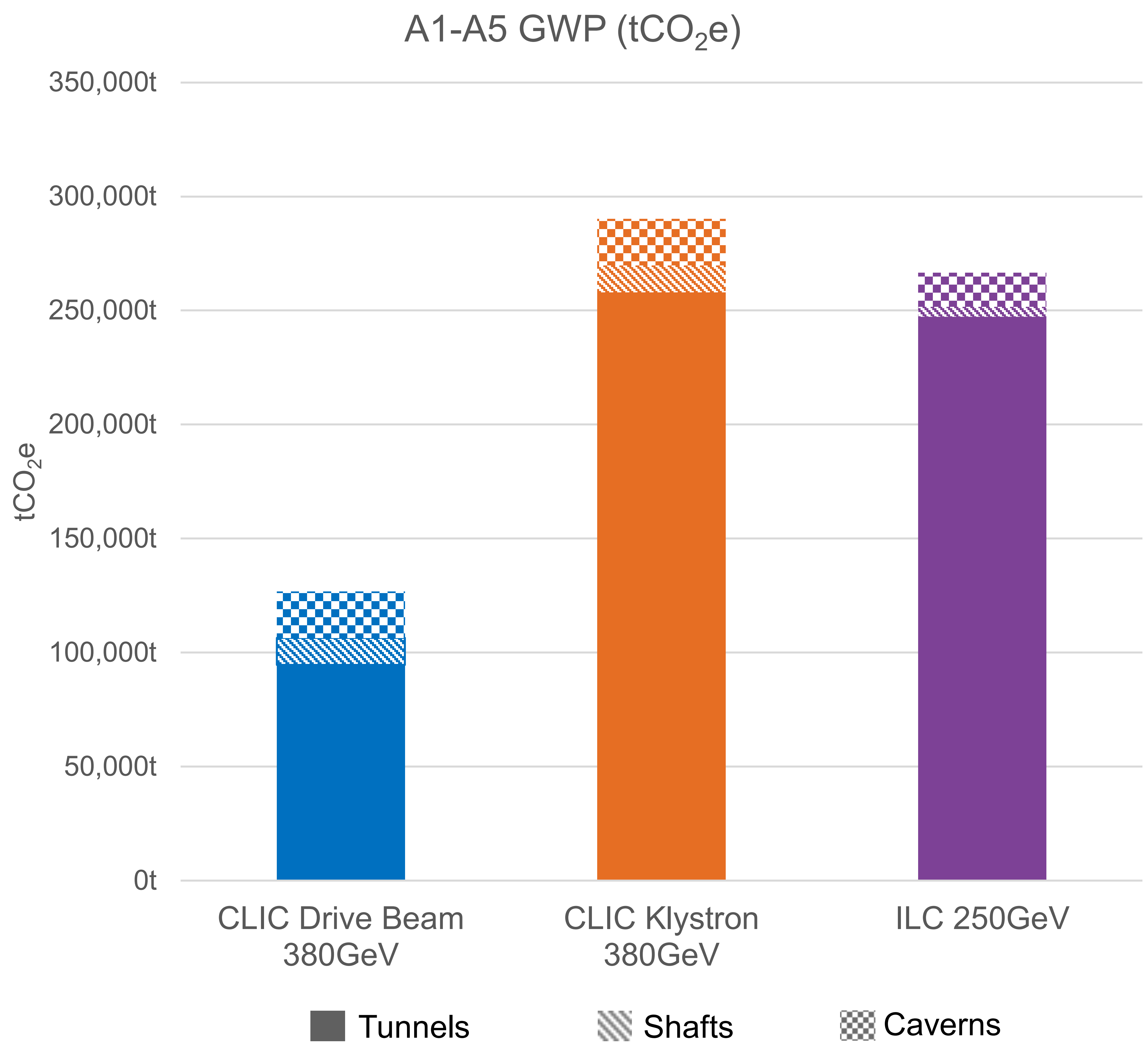
Reference: Tohoku ILC Civil Engineering Plan, 2020

System | **Sub-system** | Components | Sub-components

CLIC & ILC

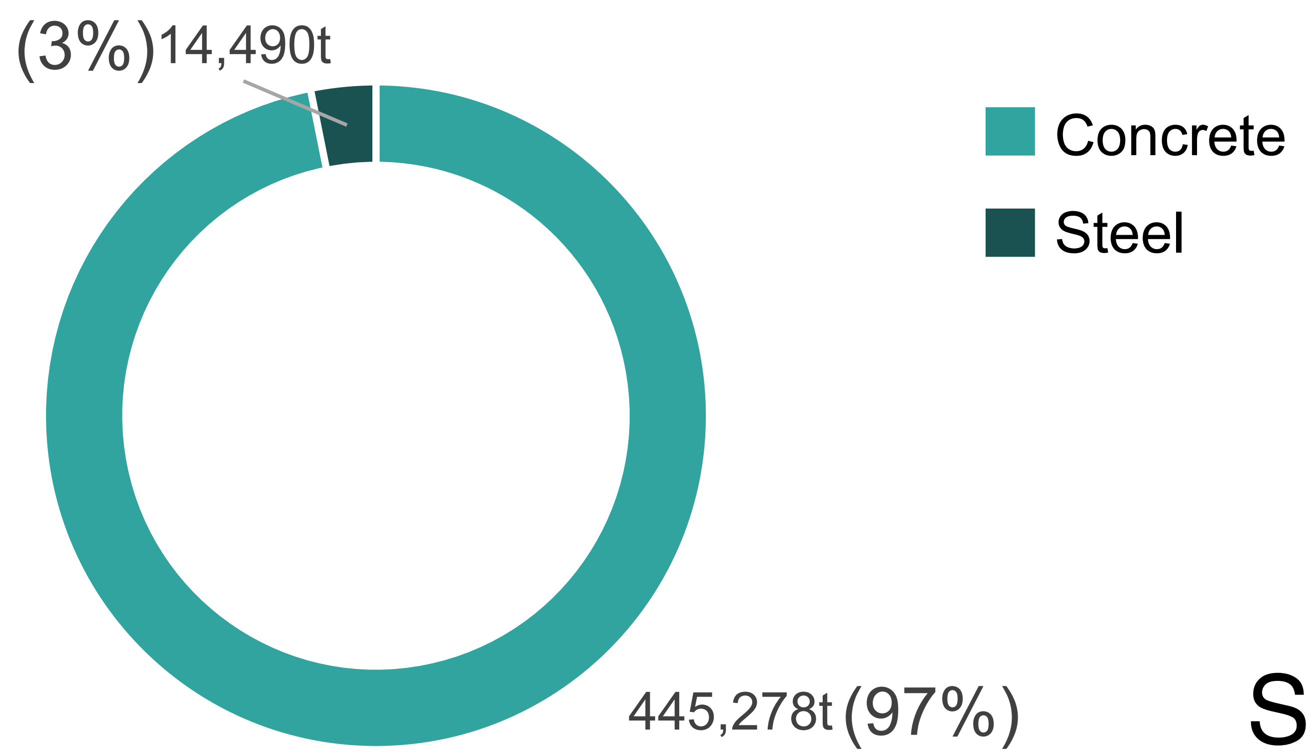
ARUP

A1-A5 Global Warming Potential (tCO_2e)

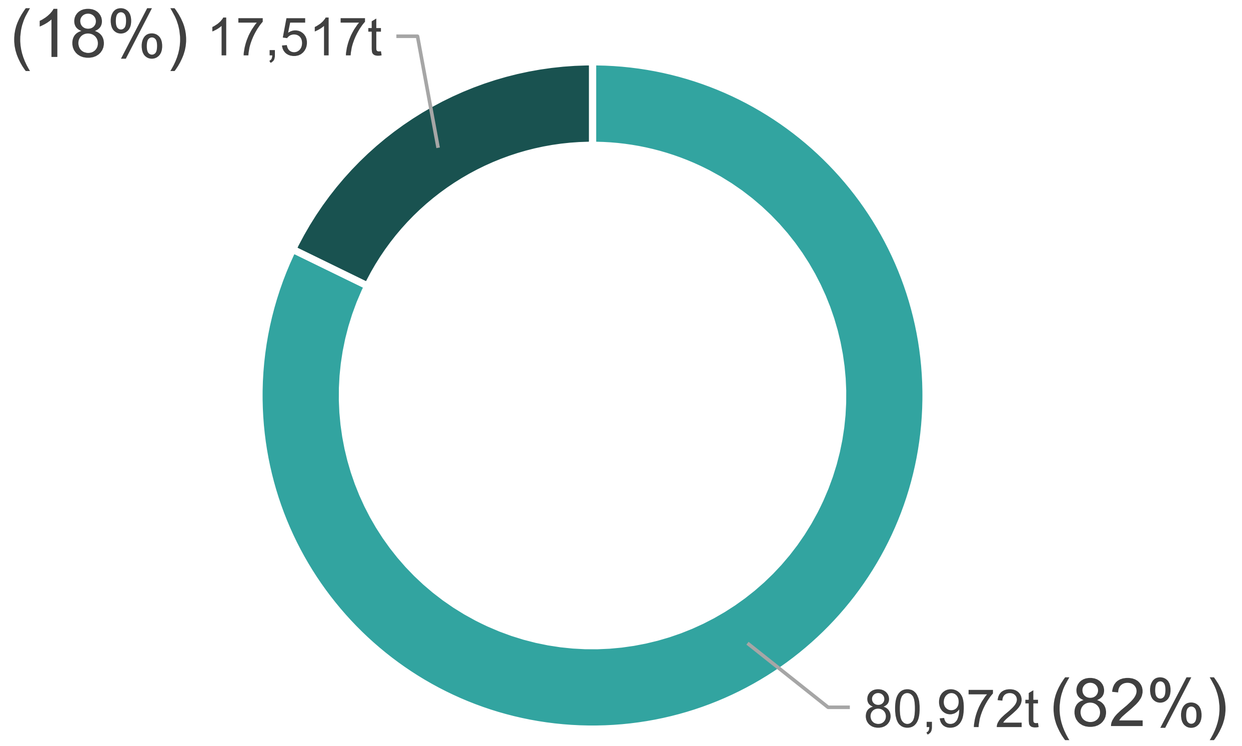


CLIC Drive Beam 380GeV

A1-A3 material breakdown (t)



A1-A3 GWP breakdown (tCO_2e)



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System	Sub-system	Components	Sub-components

ILC 250GeV

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Tunnels reduction opportunities

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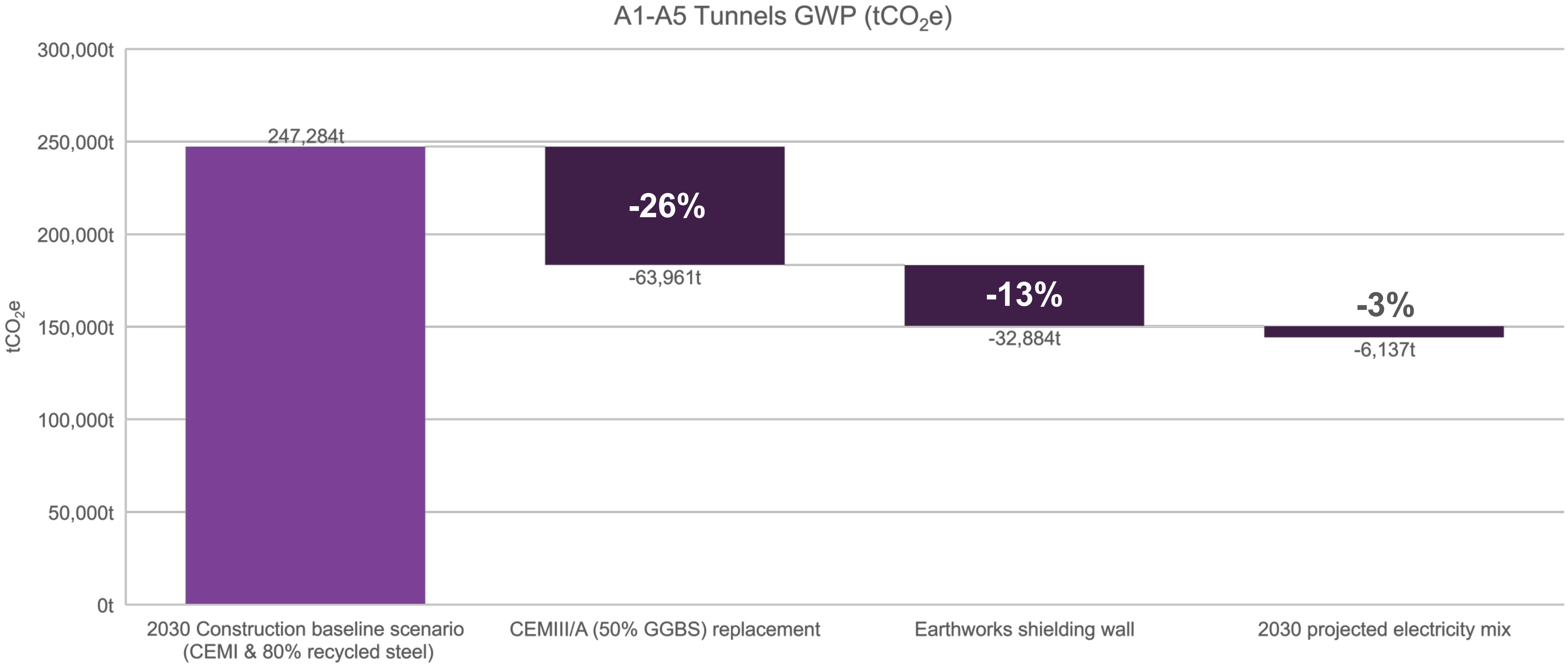
42% possible A1-A5 GWP reduction



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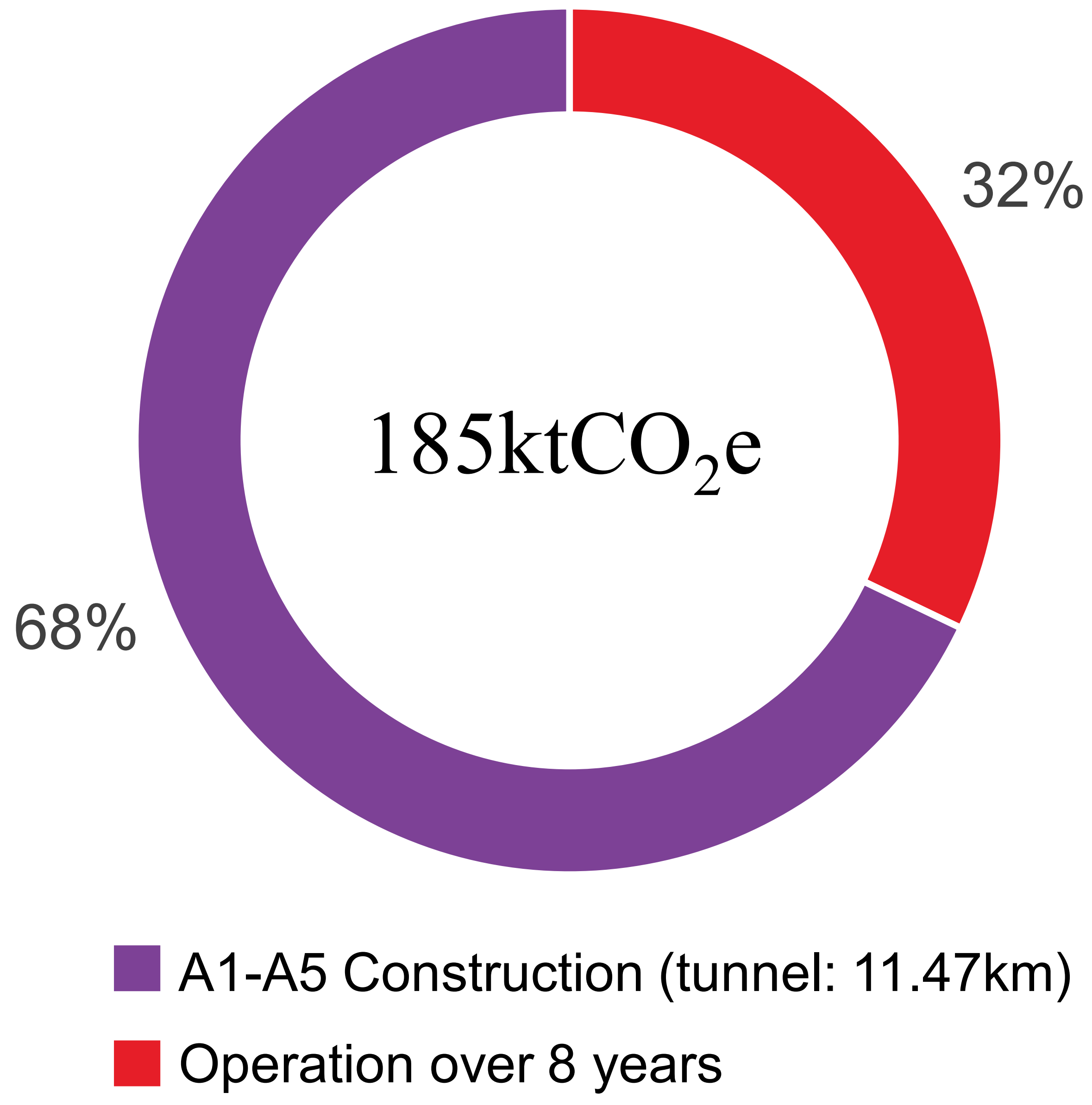
CLIC Drive Beam

A1-A5 Global Warming Potential (tCO_2e)

*Operational estimates provided by CERN. Based on a projected electricity mix in 2050 (50% nuclear, 50% renewables).

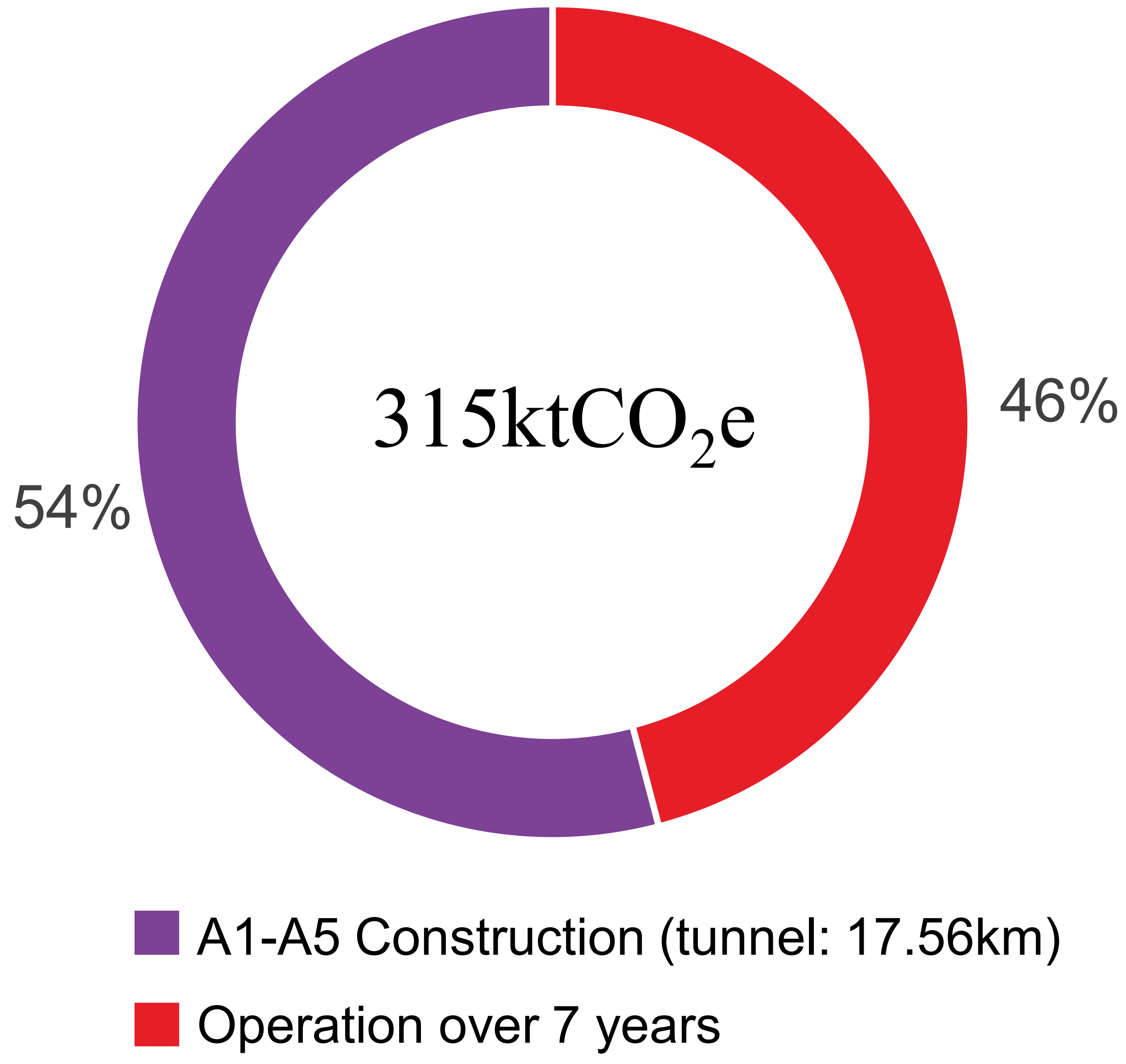
380GeV

Annual CO_2e of operations is 6% of embodied carbon
A1-A5 GWP is equivalent to 1.7 decades of running accelerator



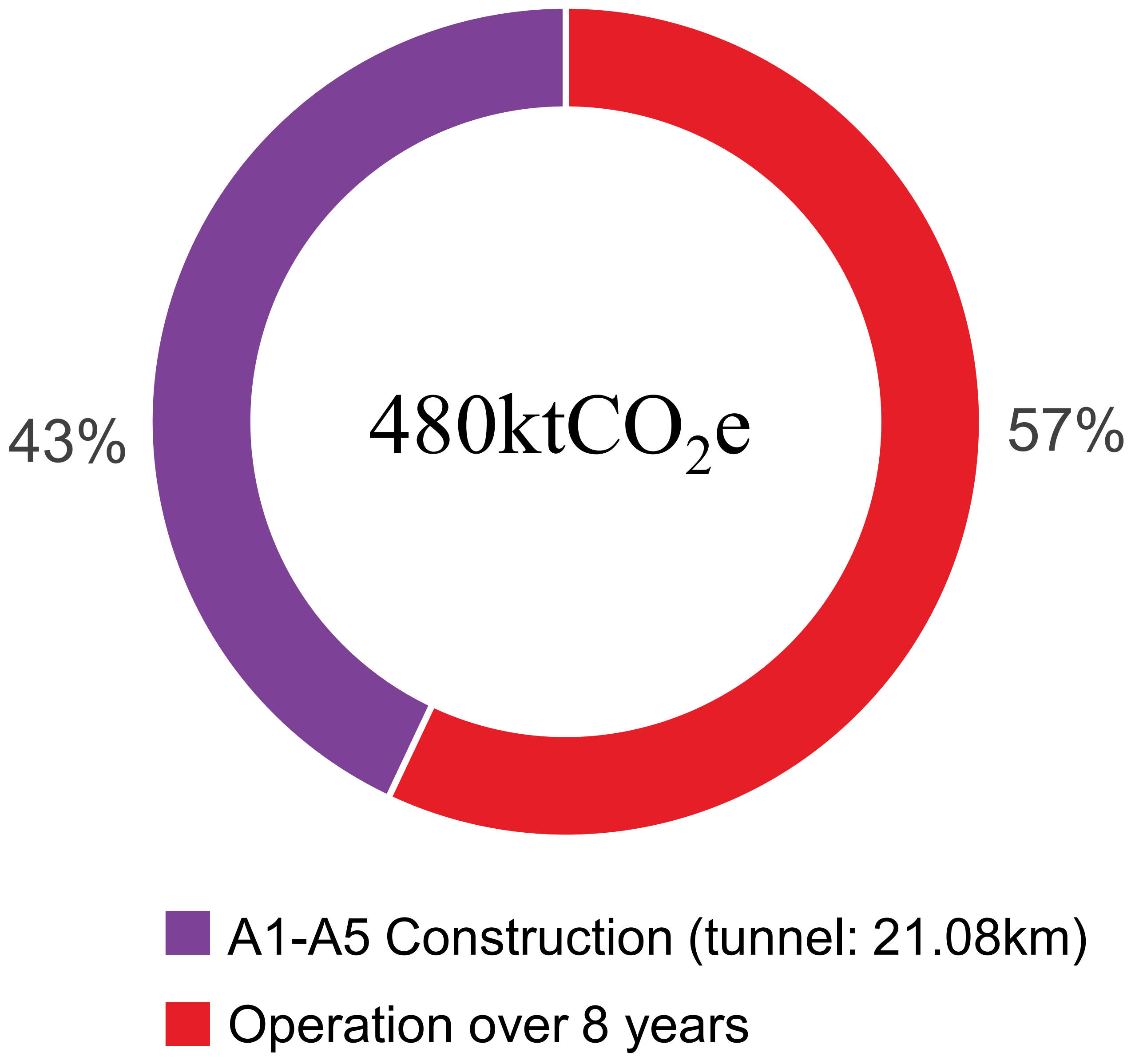
1.5TeV

Annual CO_2e of operations is 12% of embodied carbon
A1-A5 GWP is equivalent to 0.8 decades of running accelerator



3TeV

Annual CO_2e of operations is 17% of embodied carbon
A1-A5 GWP is equivalent to 0.6 decades of running accelerator

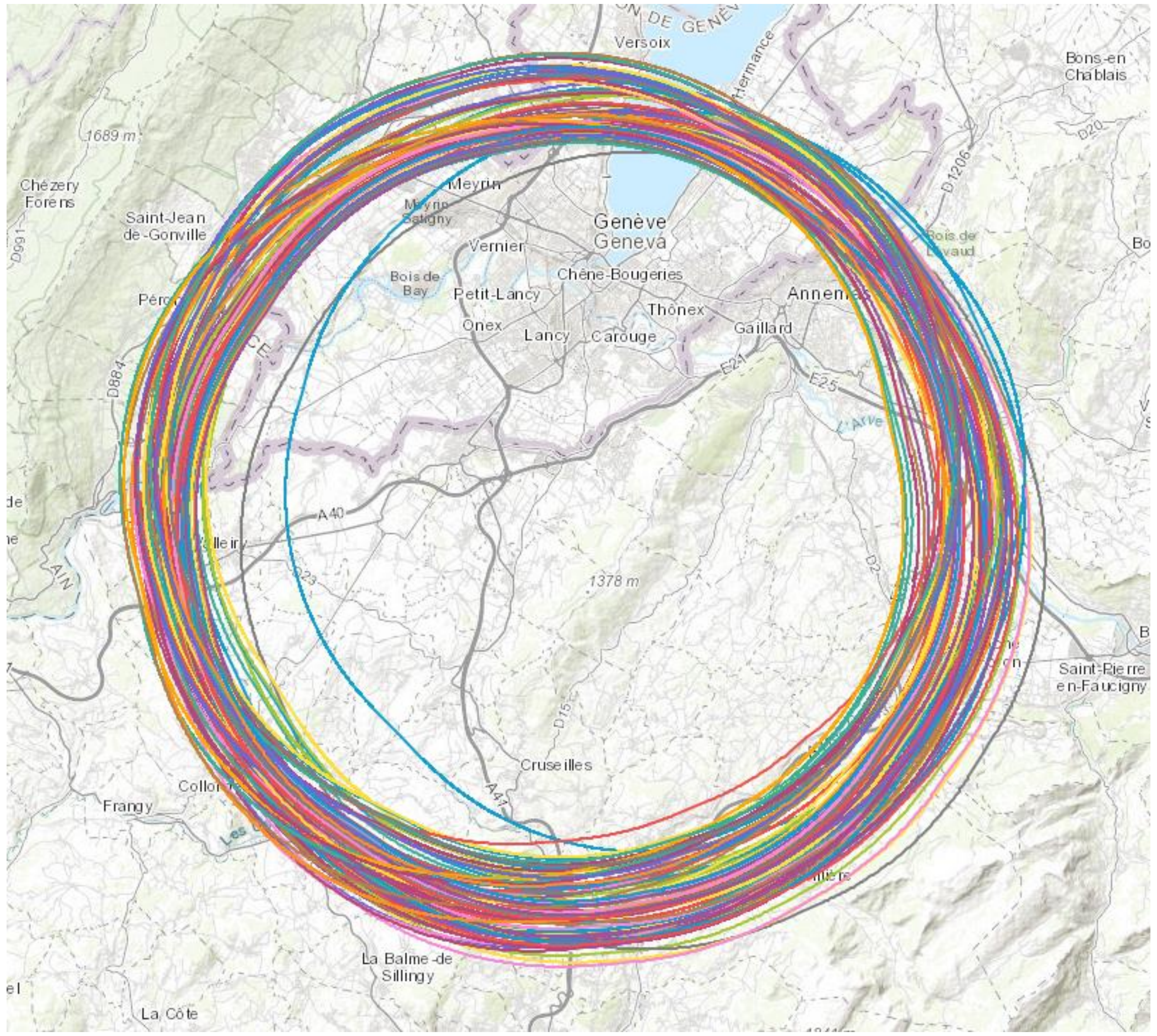


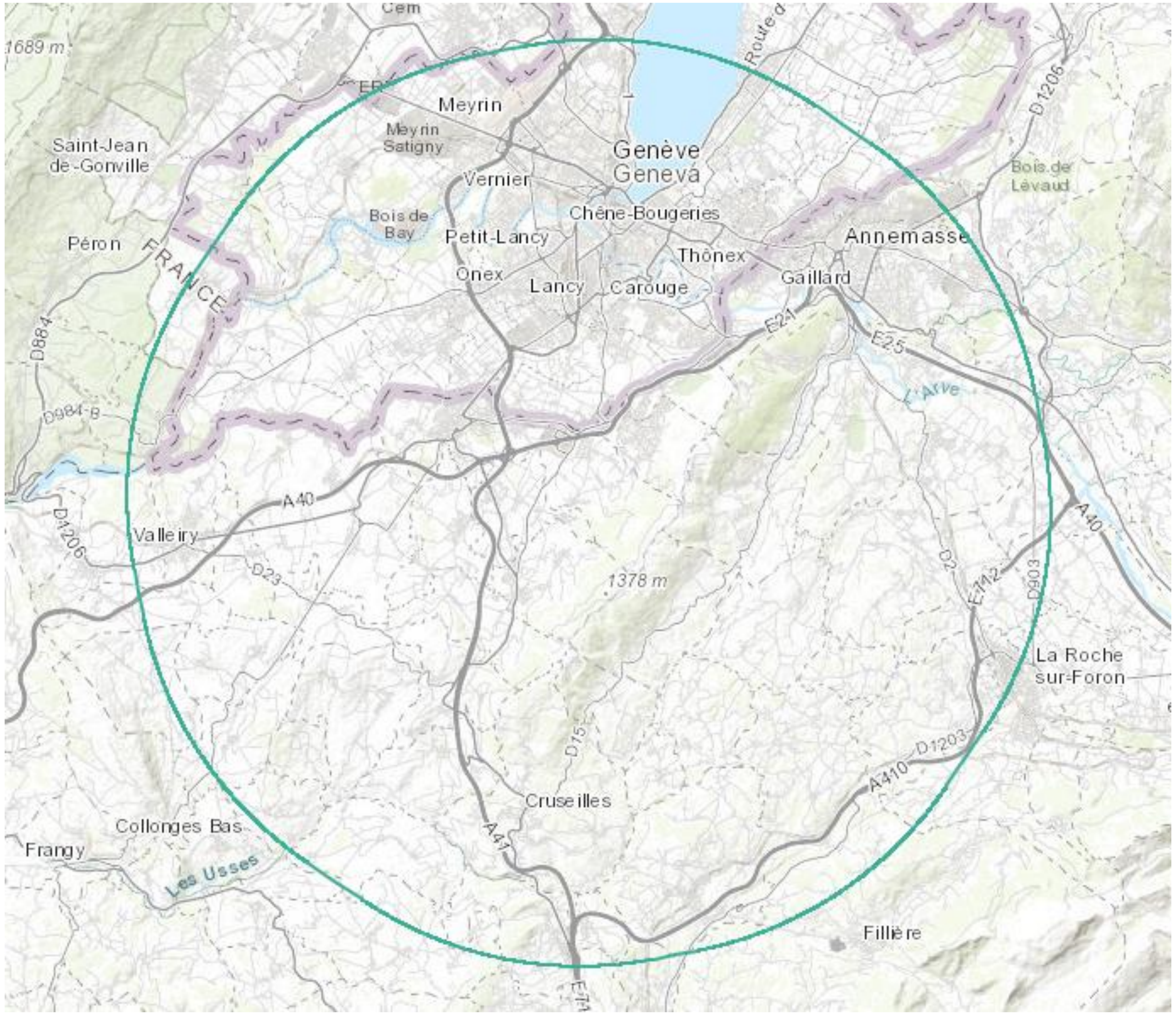
FCC/CEPC

PA31-3.2 Alignment

L. Bromiley

90.6 km circumference
Swiss molasse basin
Lake crossing
River (moraine) crossings
Mountain topography
Geneva metropolitan area





Civil Engineering Sub Surface

L. Bromiley

8 surface sites

13 shafts

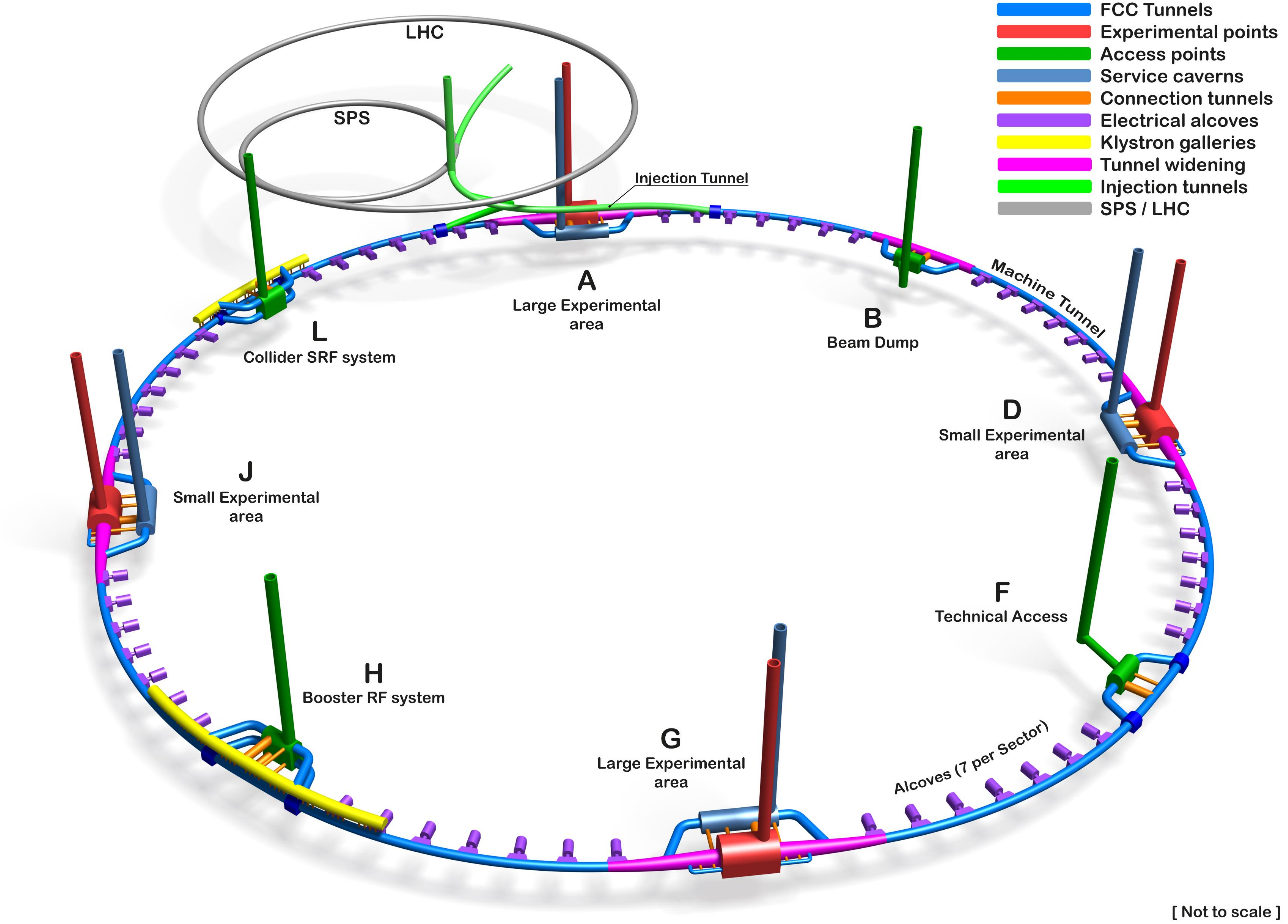
4 experiment caverns

8 service caverns

Beam dump

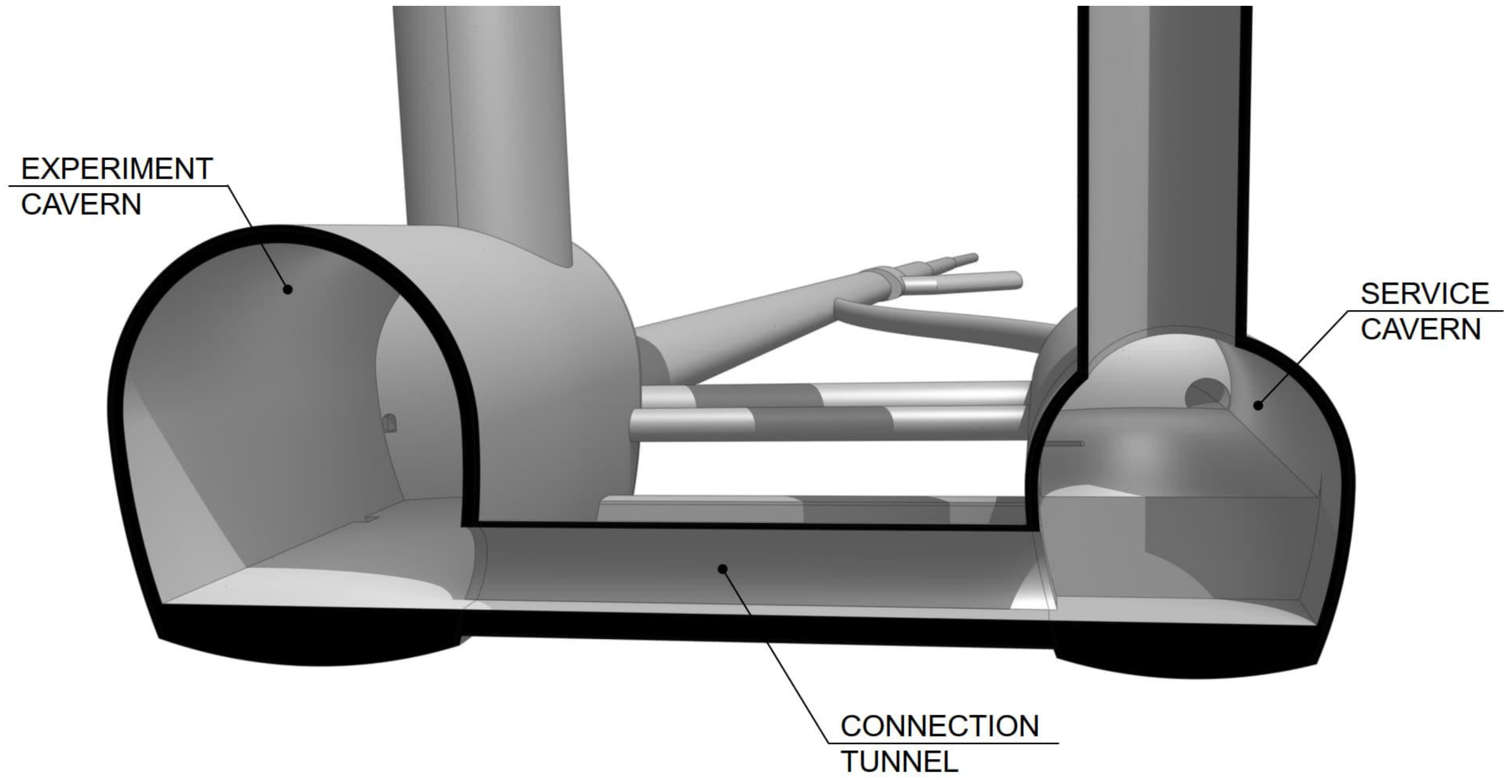
RF klystron galleries

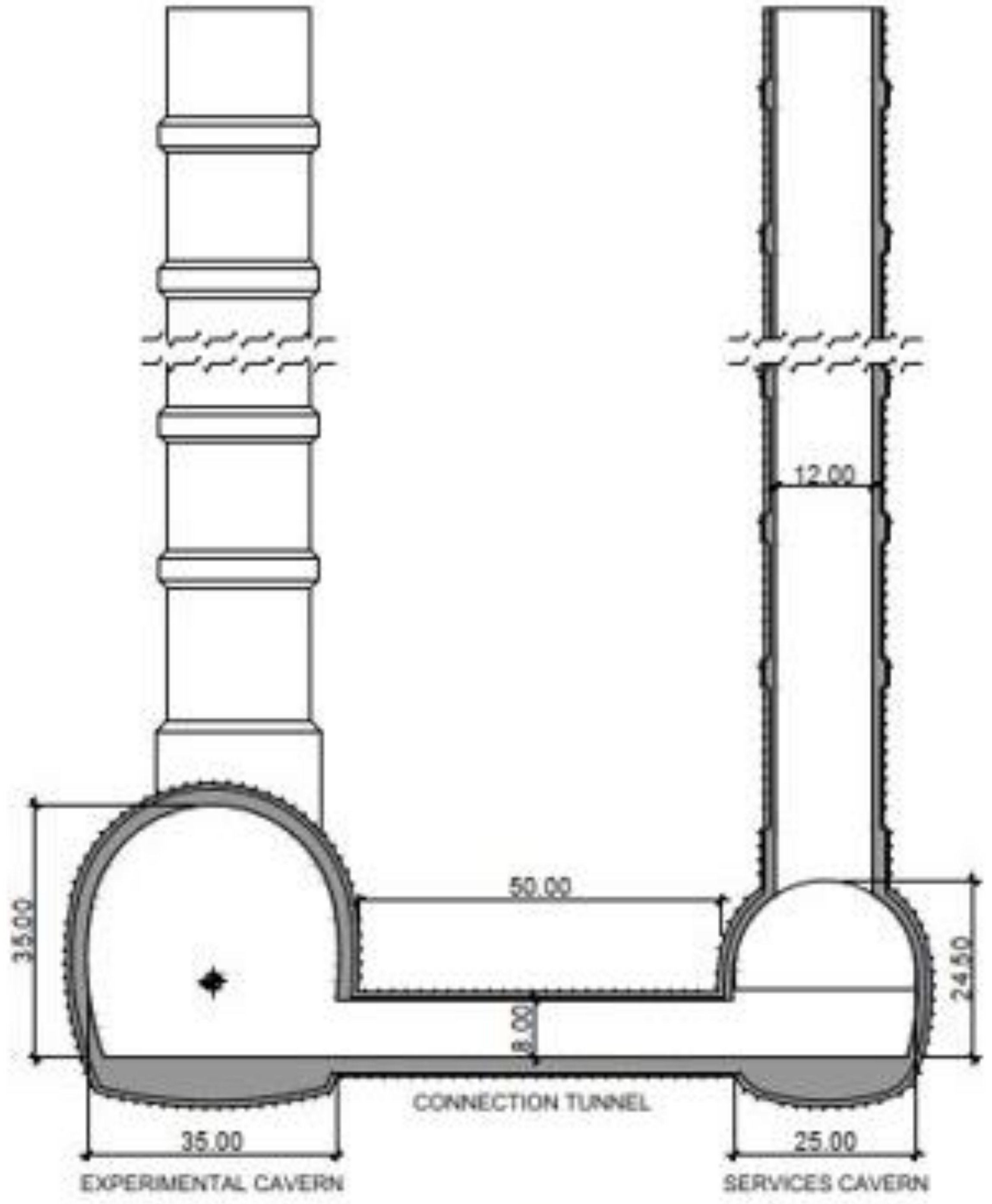
SPS injection lines



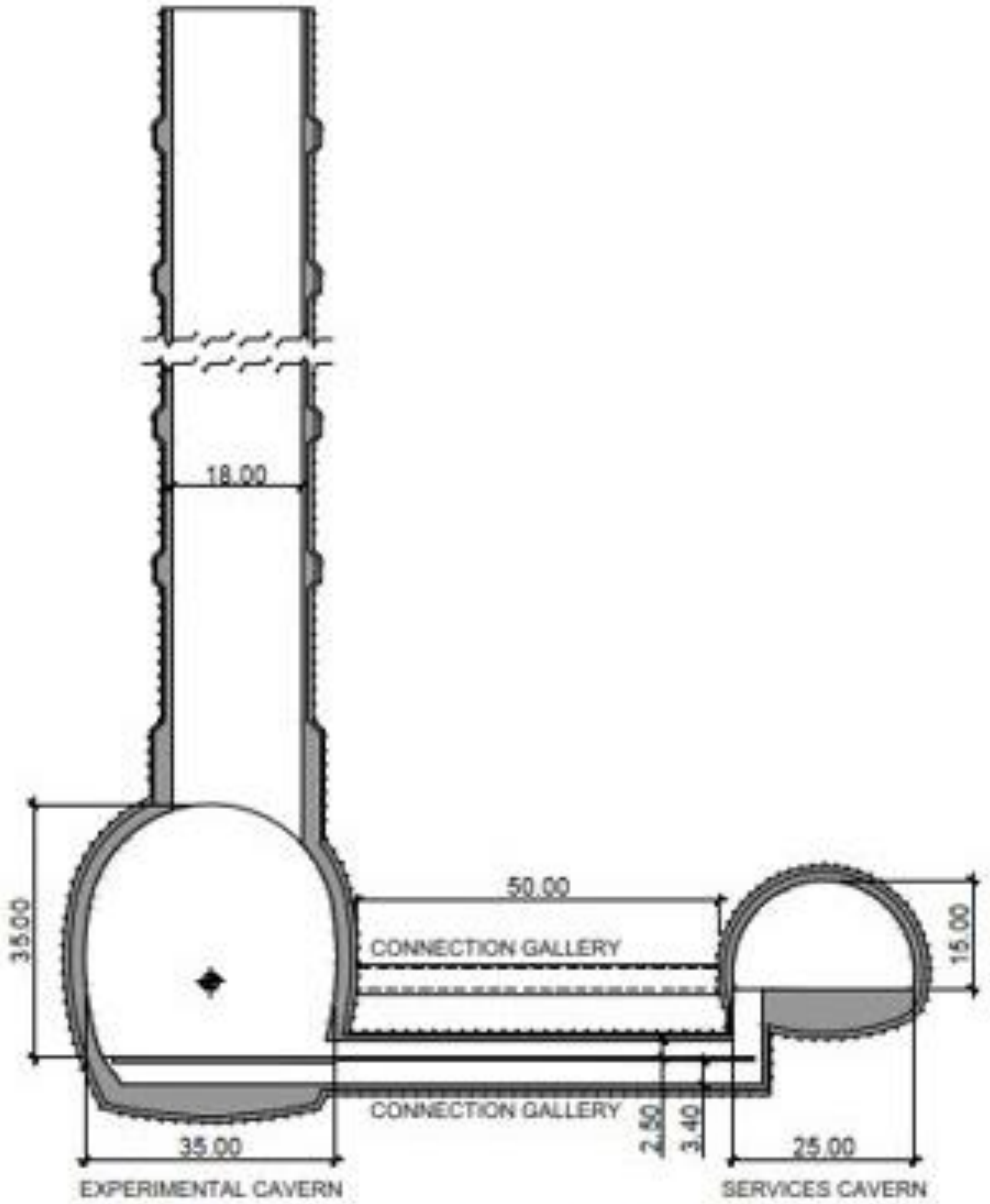
Caverns

L. Bromiley





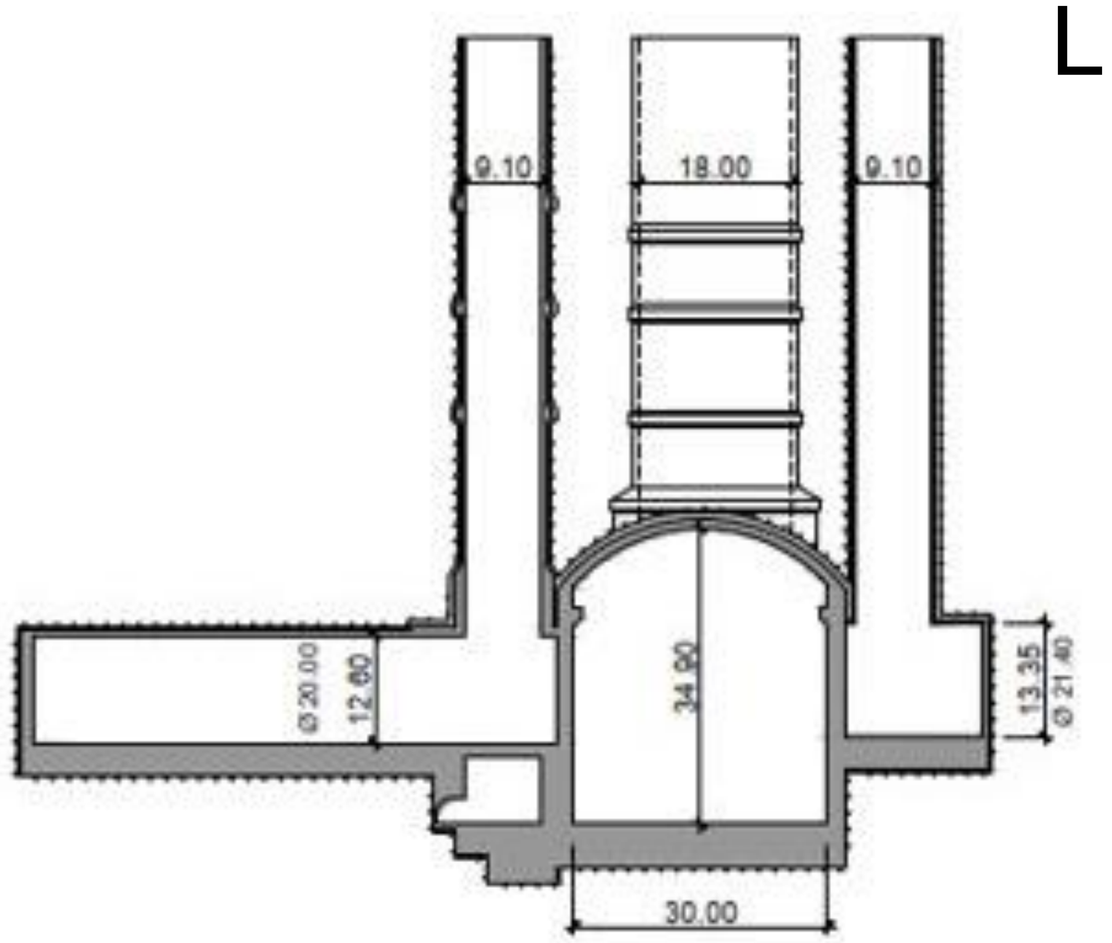
SECTION A-A
1/500



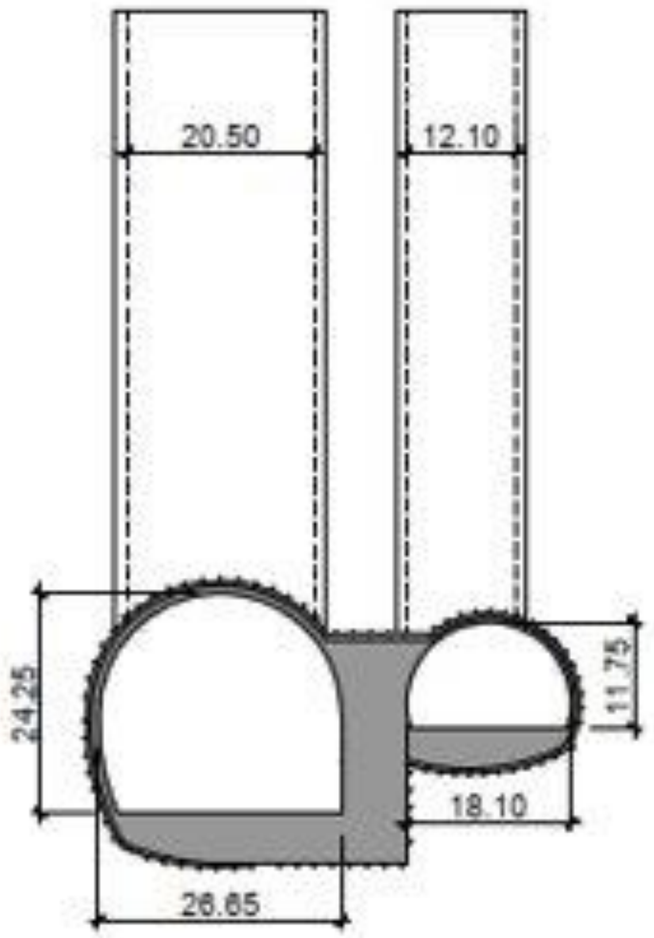
SECTION B-B
1/500

FCC

Credit: Angel Navascues Cornago



ATLAS (LHC)



CMS (LHC)

Shafts

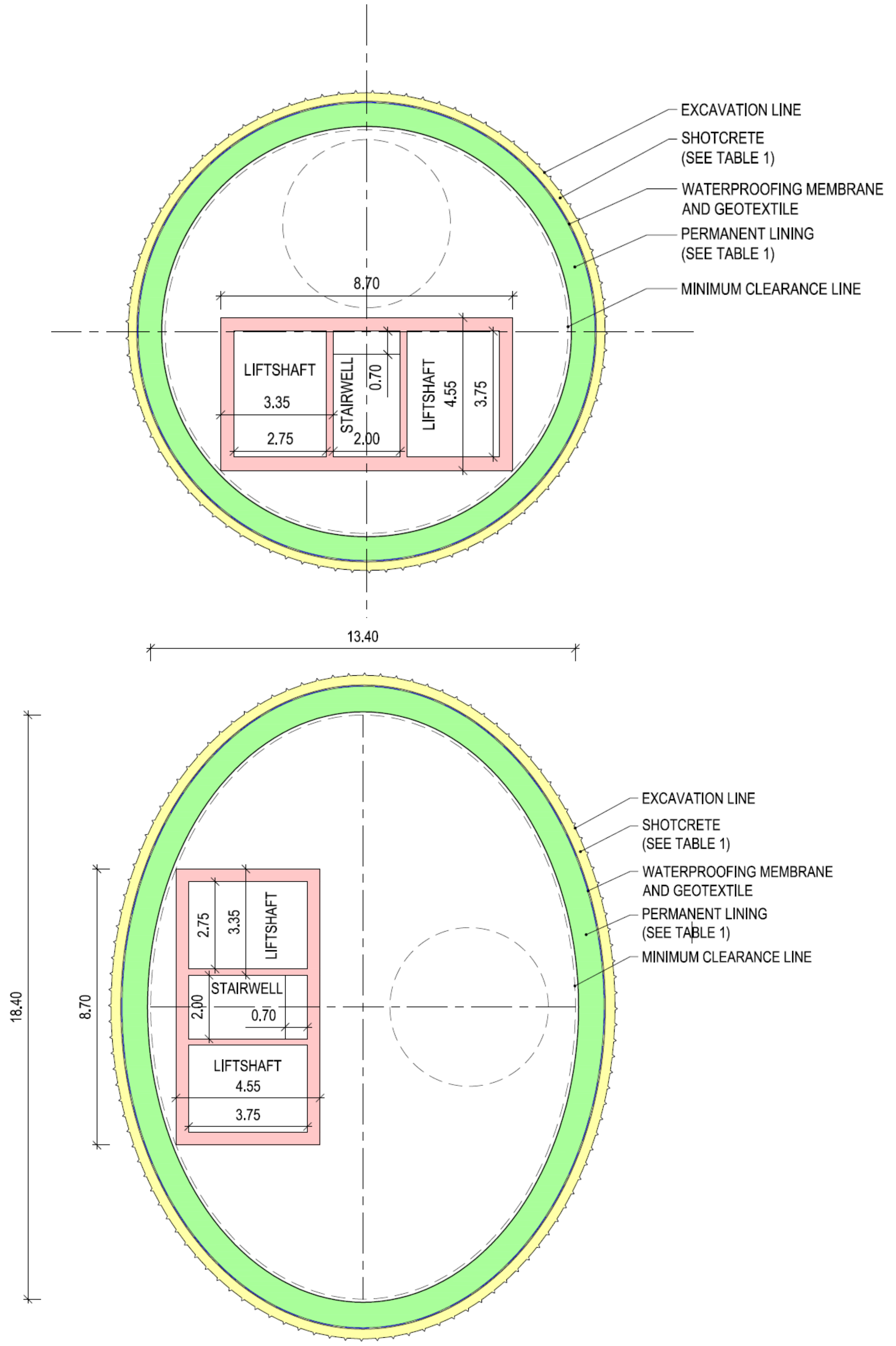
L. Bromiley

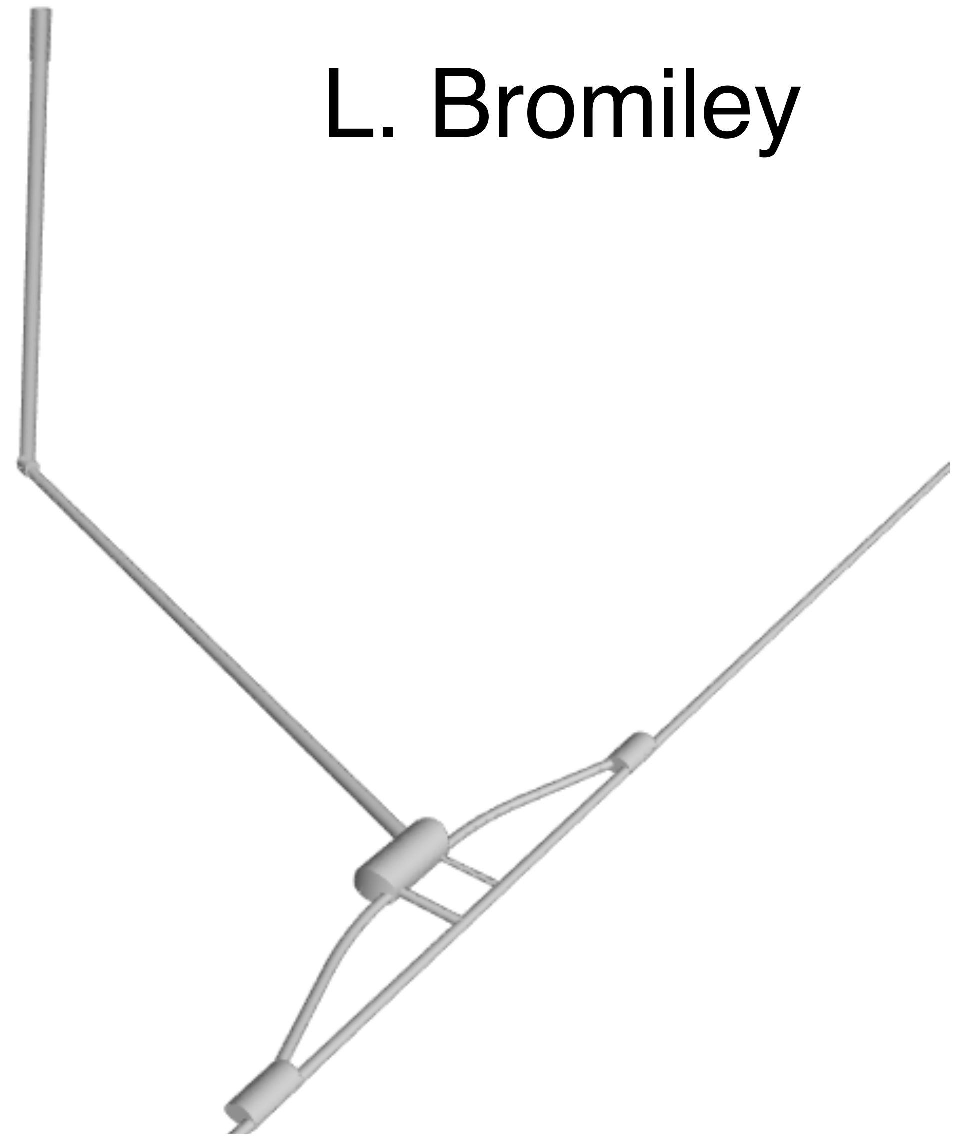
Shaft depths, 180m to 400m

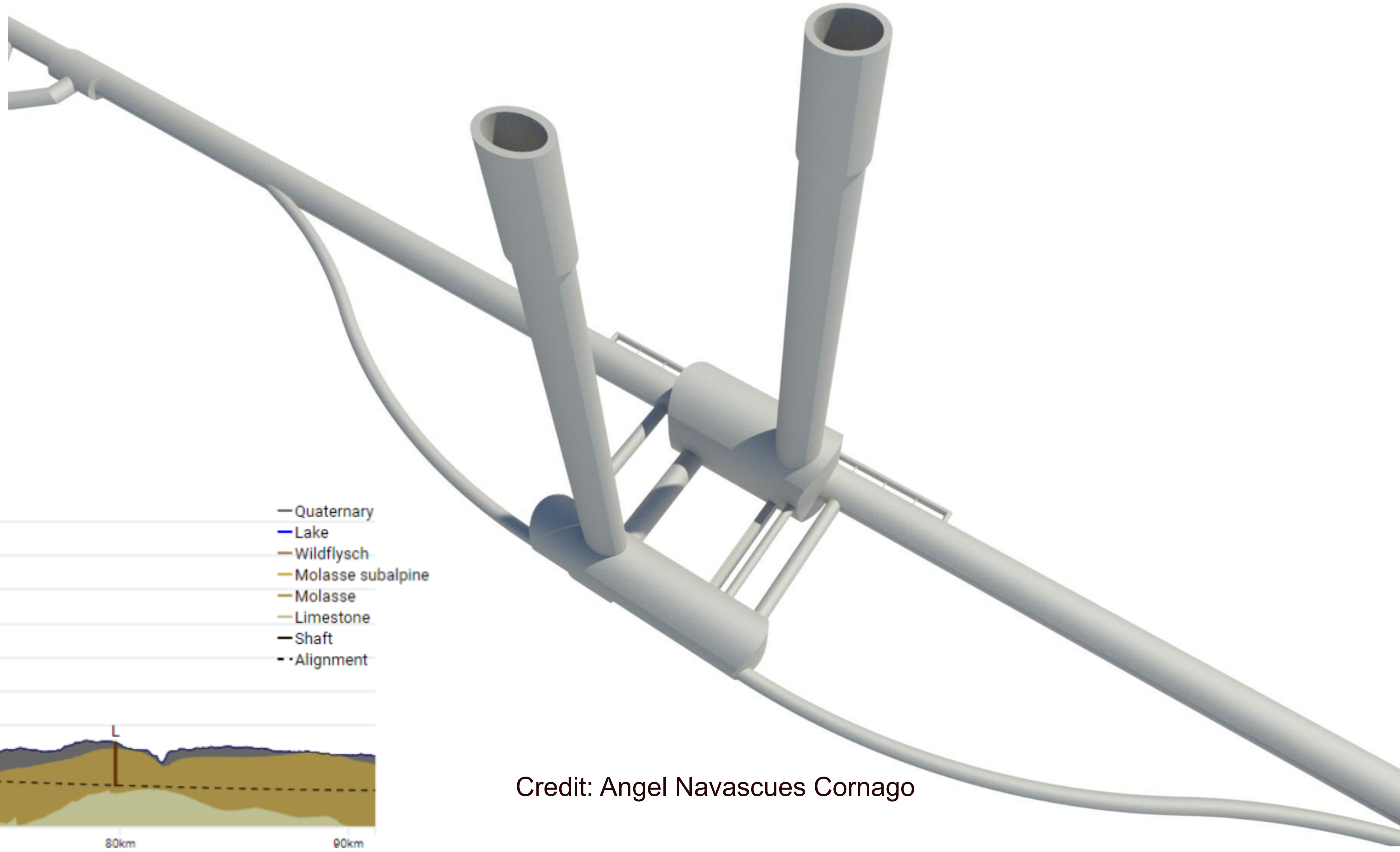
18m elliptical

18m circular

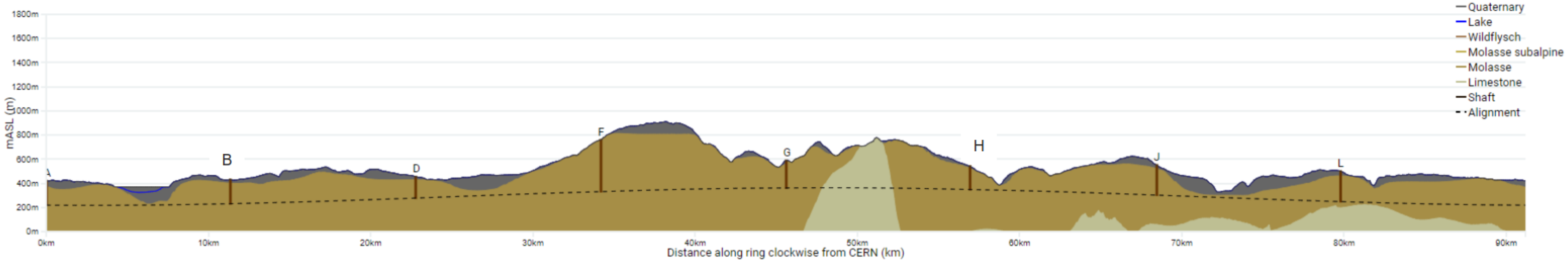
12m circular







Credit: Angel Navascues Cornago



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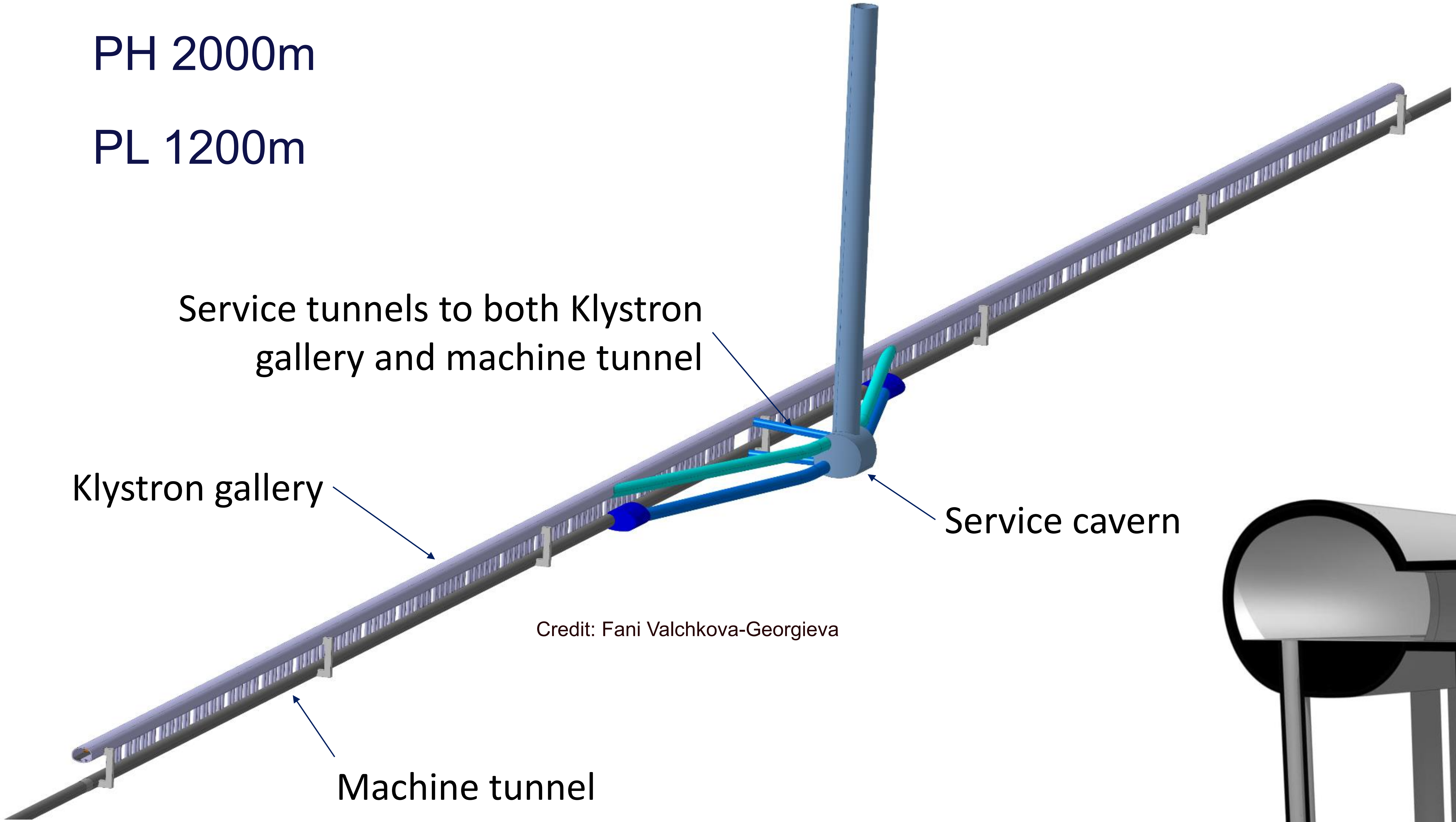
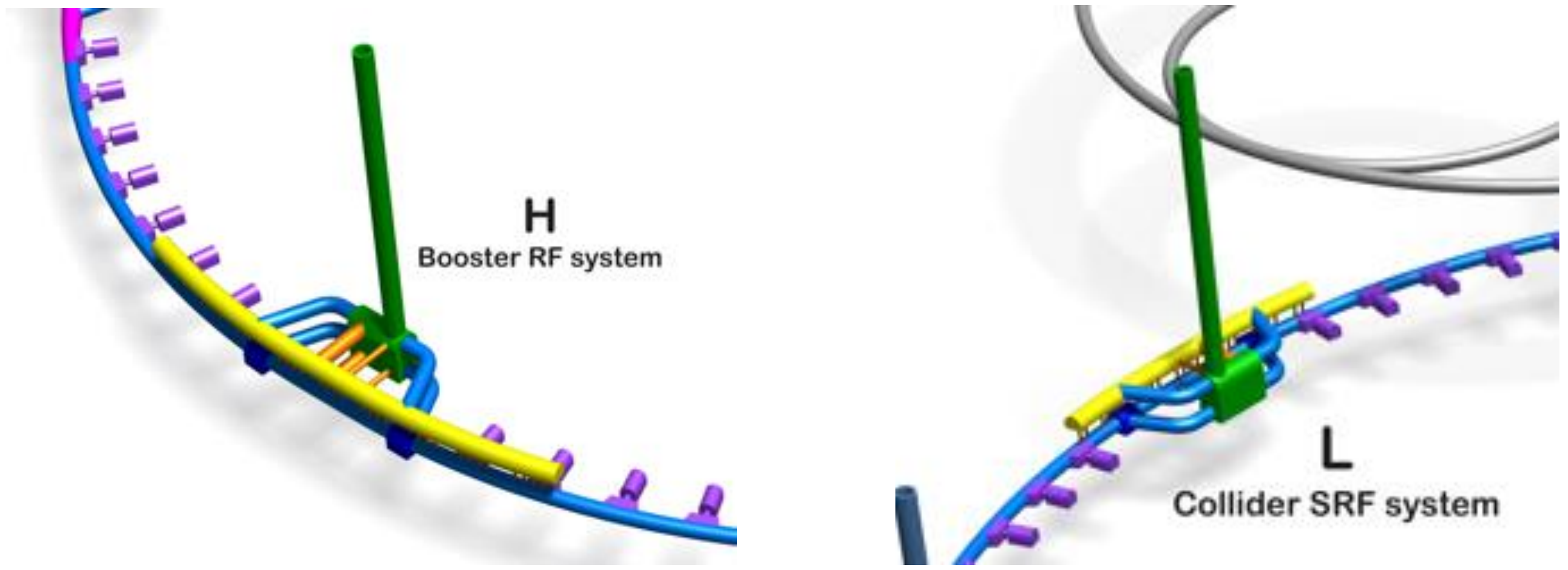
Klystron Galleries

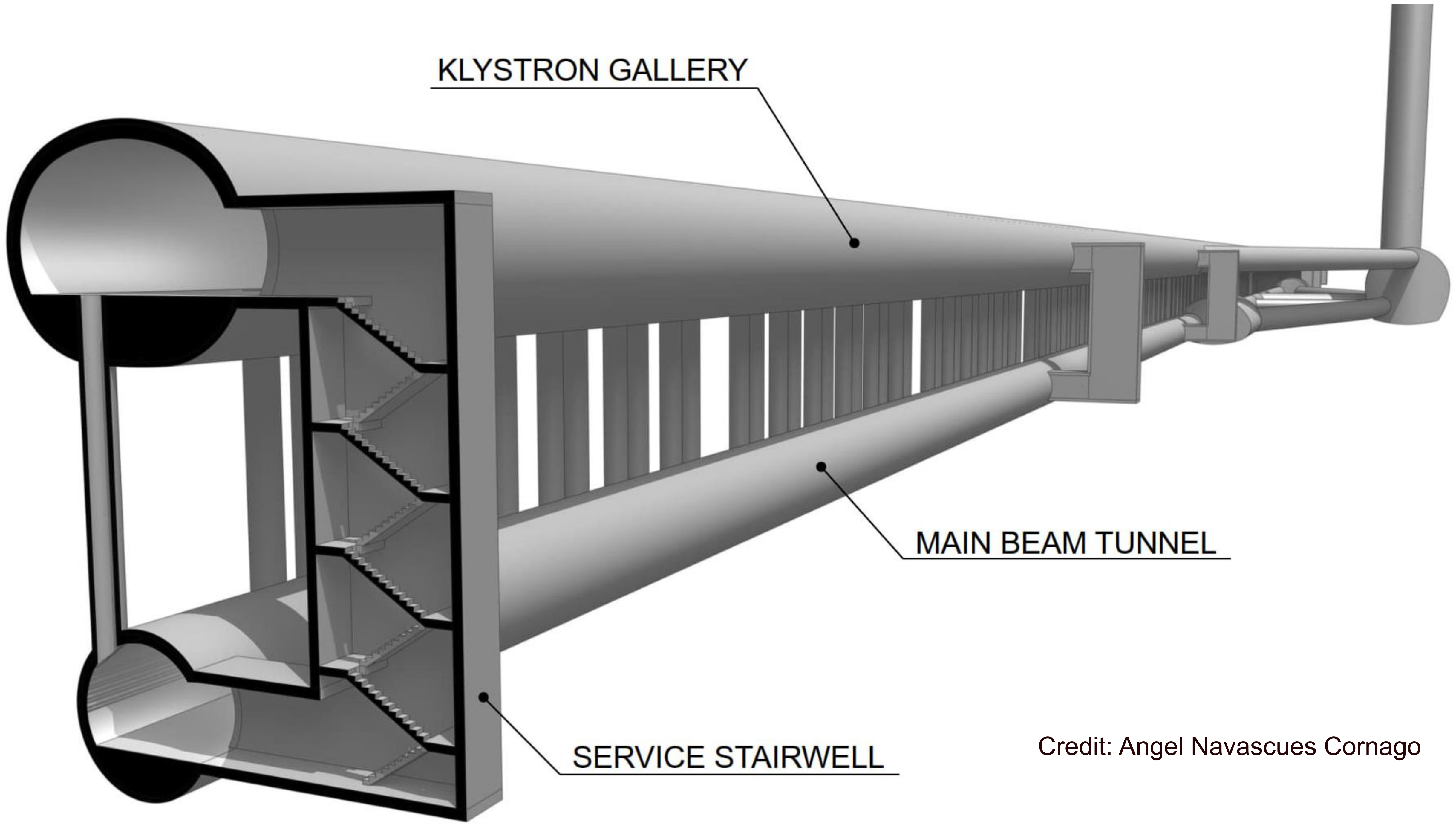
PH 2000m

PL 1200m



Credit: Fani Valchkova-Georgieva





Credit: Angel Navascues Cornago

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MATEX Study

Study to estimate quantity and disposal of excavated material

Baseline TBM layout and direction of drives

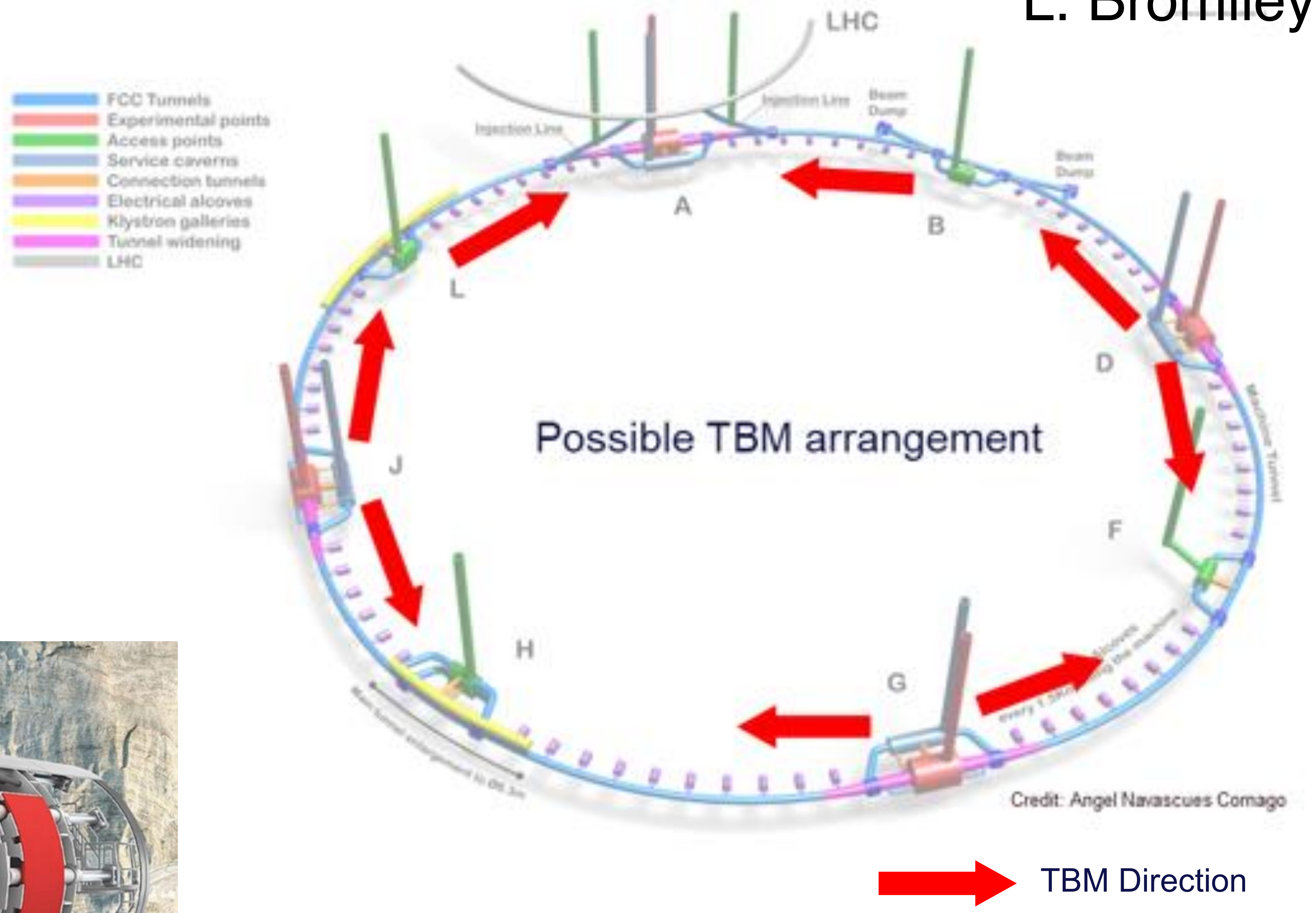
Balance of material between France and Switzerland

96% molasse

3% limestone

1% moraine

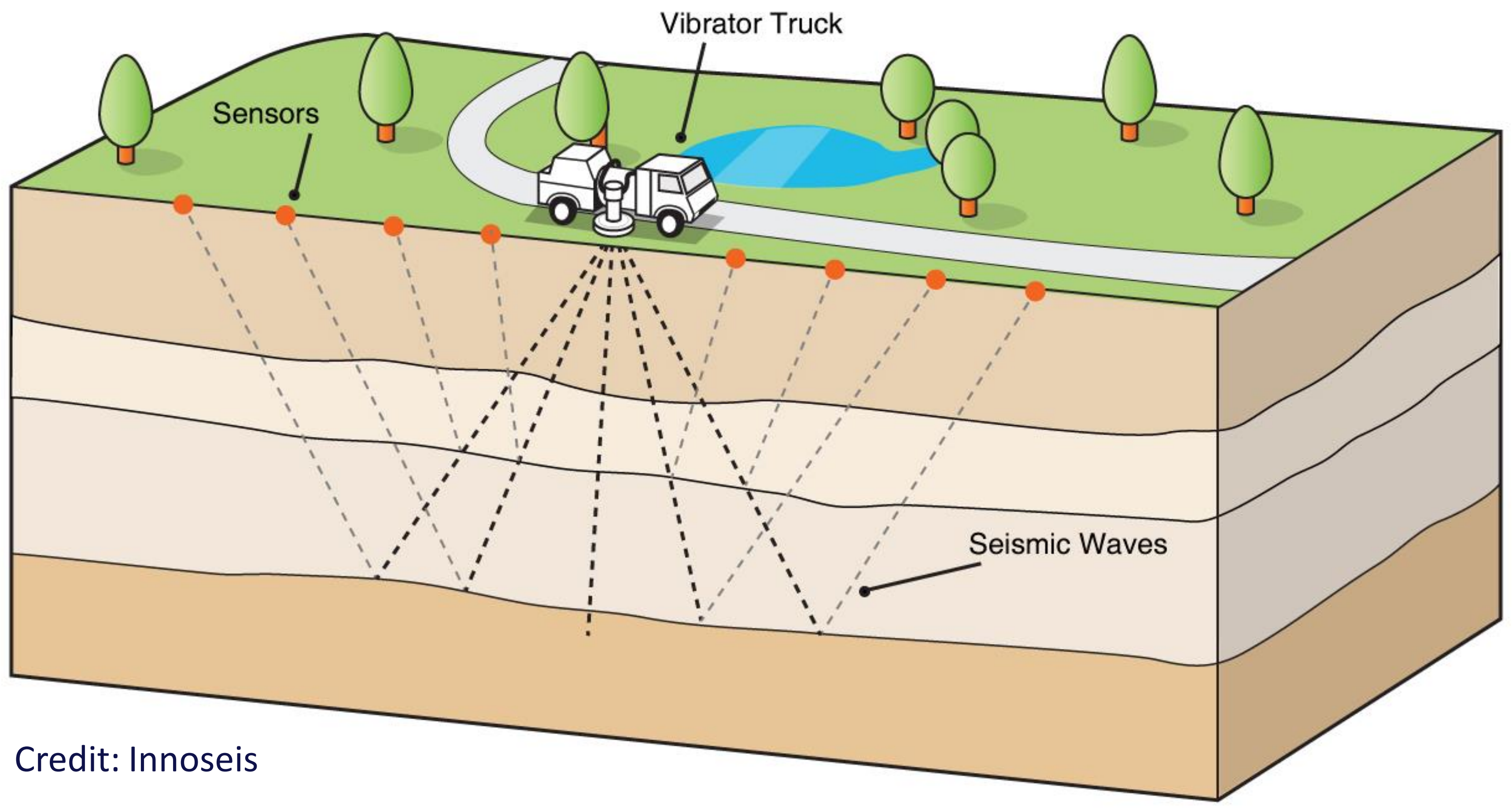
Total, 8,100,000 m^3



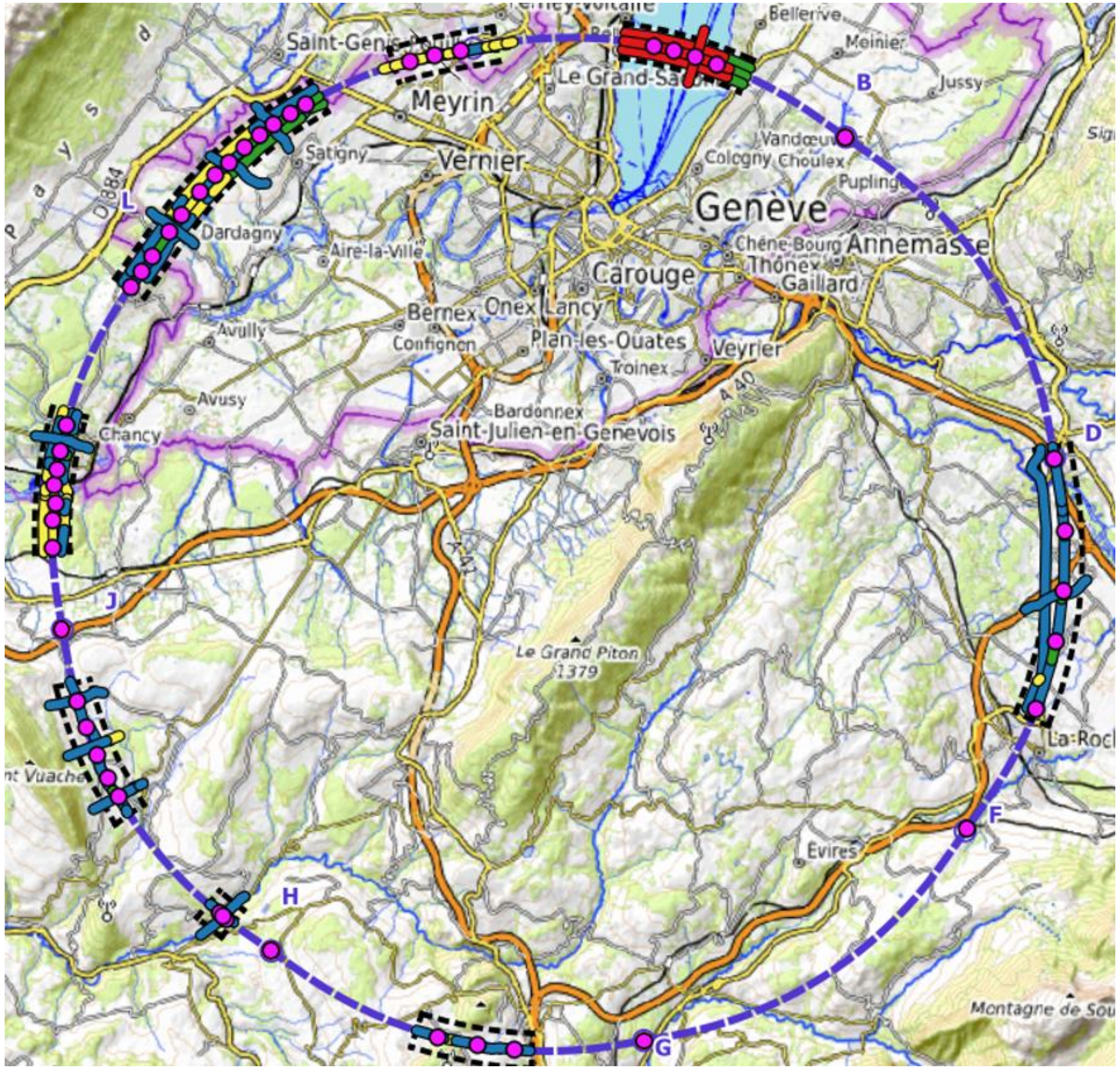
Base. TBM	A	B	D	F	G	H	J	L	Inj. Prevessin	Inj. SPS	Total
Vol.	569,119	559,922	1,288,361	153,735	1,378,880	291,486	1,300,330	583,564	28,867	82,197	6,236,461
Bulk Vol.	739,855	727,898	1,674,869	199,856	1,792,544	378,932	1,690,429	758,633	37,527	106,856	8,107,399
% of Total	9%	9%	21%	2%	22%	5%	21%	9%	0%	1%	
Vol. France	534,959	42,143	1,204,564	153,735	1,378,880	291,486	1,300,330	201,784	28,867	39,638	5,176,386
% France	94%	8%	93%	100%	100%	100%	100%	35%	100%	48%	83%
Vol. Suisse	34,160	517,772	83,797	-	-	-	-	381,754	-	42,560	1,060,043
% Suisse	6%	92%	7%	0%	0%	0%	0%	65%	0%	52%	17%

L. Bromiley

Areas of Geological Uncertainty



Credit: Innoseis



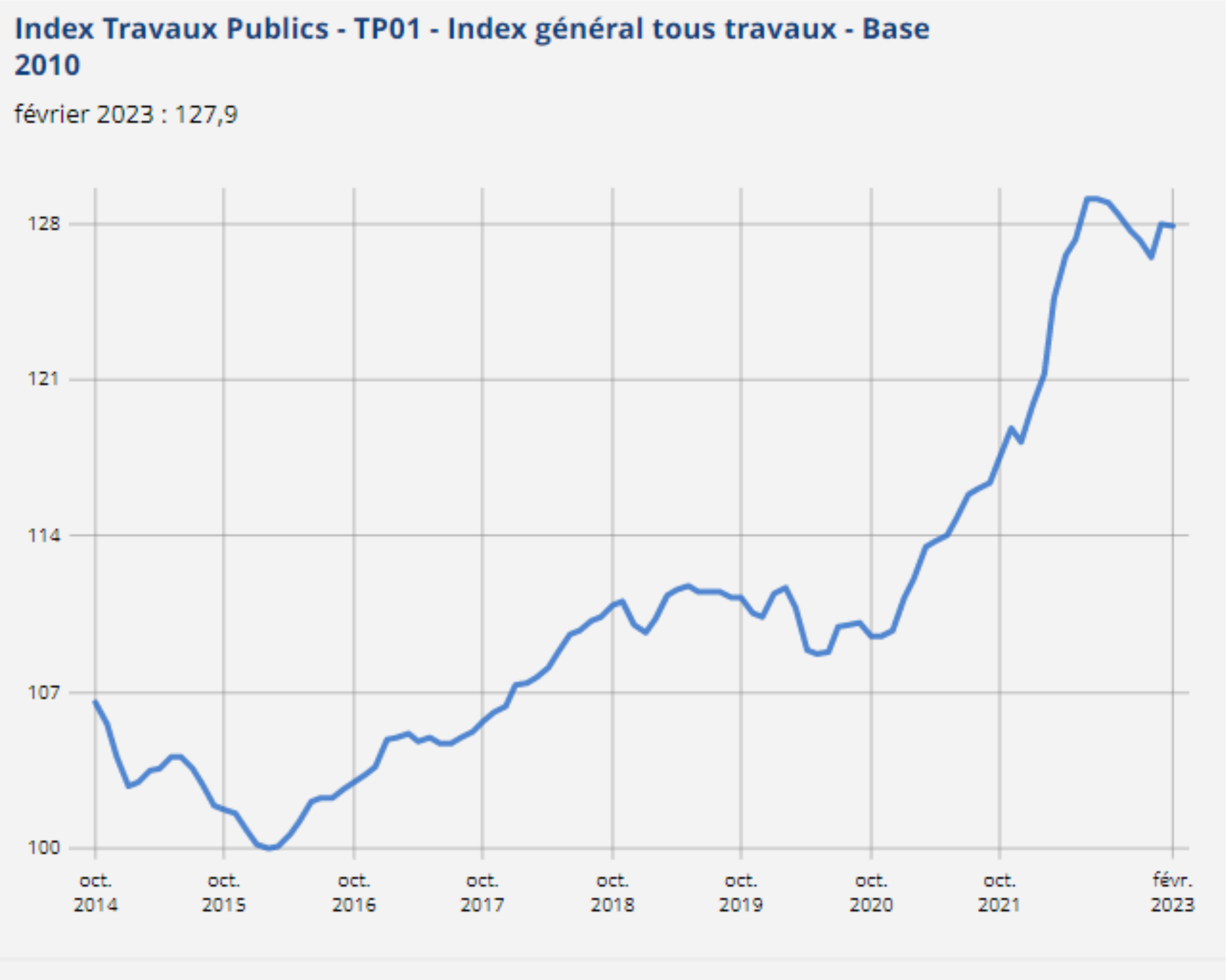
Construction Schedule Study

Construction schedule for each task

TILOS linear infrastructure tool

Bottom up cost estimate

High inflation environment



Source: https://www.insee.fr/en/statistiques/serie/001711007#Tableau

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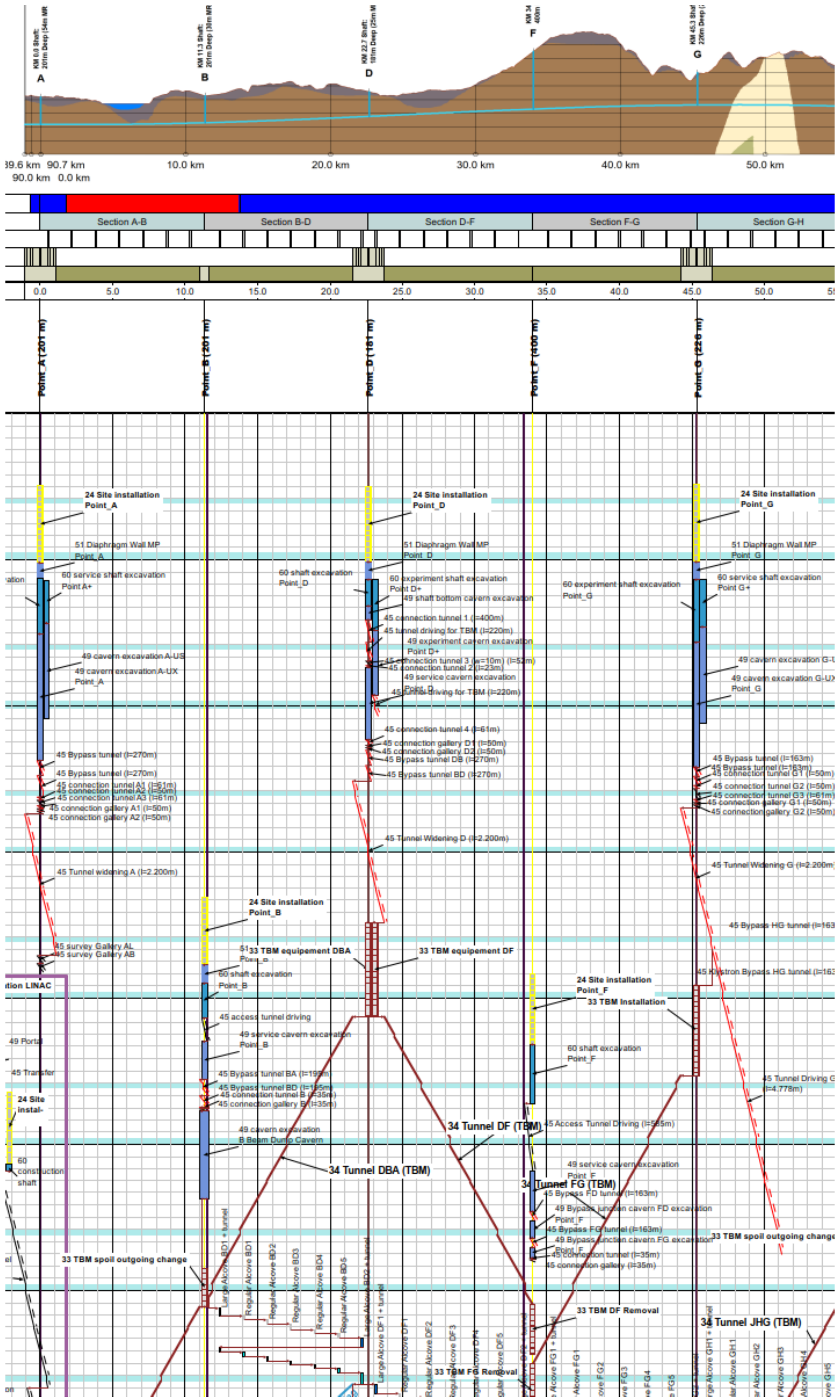
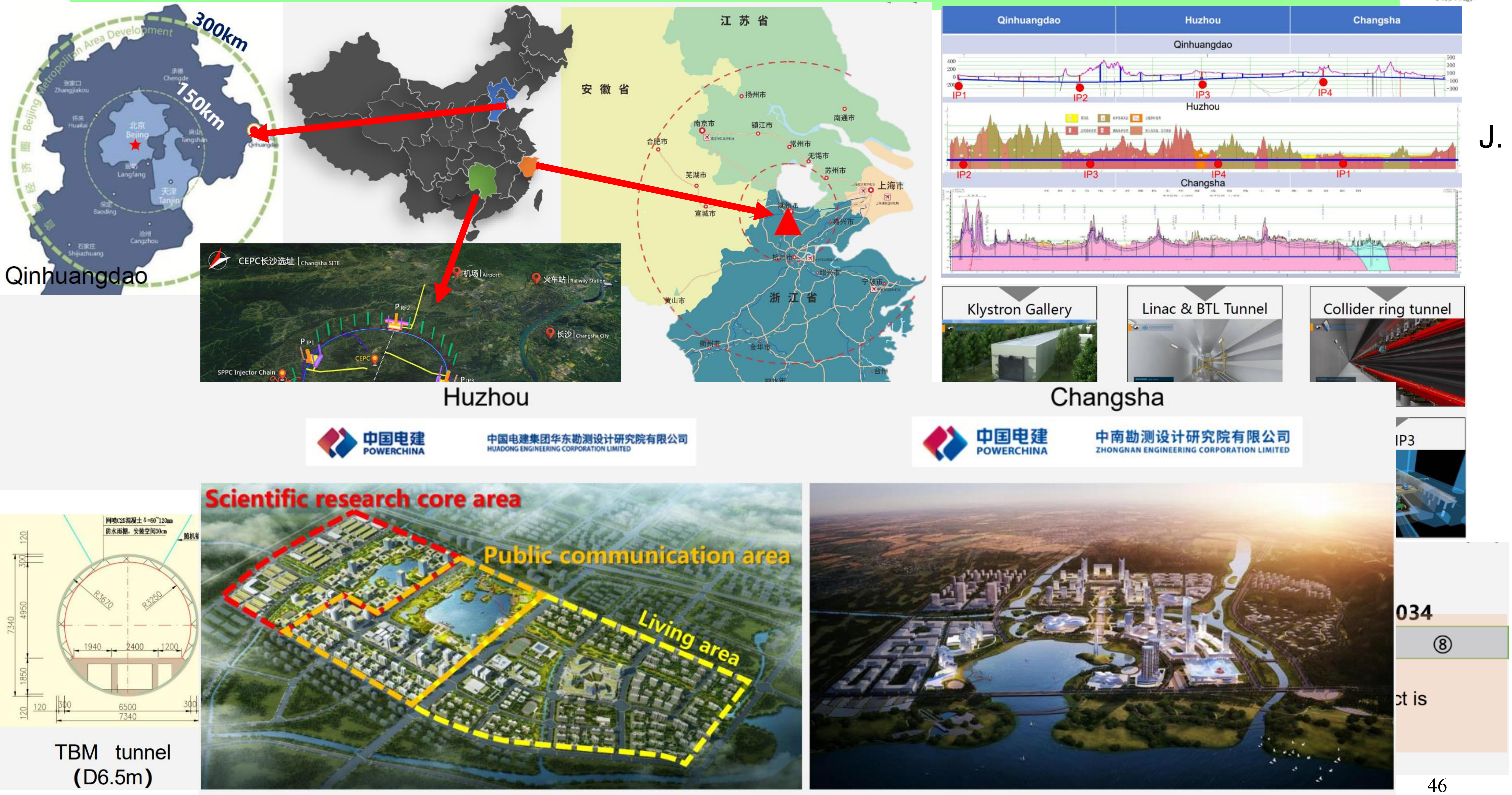


Credit: ILF

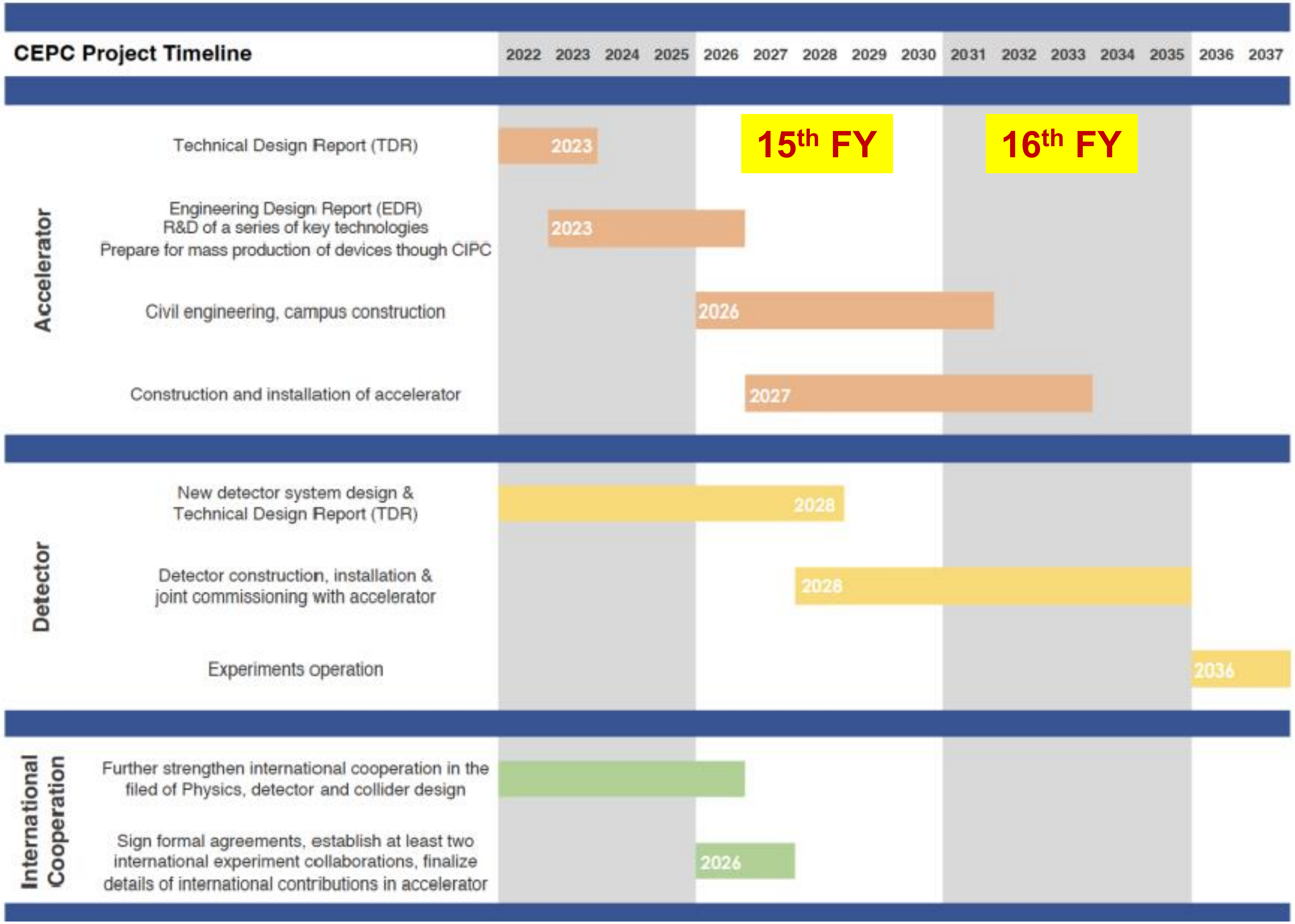
Candidate Sites and Science Cities



J. Ye

CEPC Project Timeline

- 2023: Accelerator TDR; 2026: EDR; Start construction upon approval



J. Ye

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Workshop Statement

Workshop Statement - aimed at P5

We need a Higgs Factory

We need it soon

- and it should be linear

We need R&D funding

- for ILC, C3, CLIC, PWA technologies

We need a plan towards realisation

- ILC@Japan could still be the fastest
- we are happy to investigate other sites and technologies

The linear collider is the bridge to higher energies

- beyond LHC-energy machines need decades of R&D

May 19, 2023

Statement on the Future of e^+e^- Higgs Factories from LCWS 2023

Scientists from many countries and regions are now gathered at the International Workshop on Future Linear Colliders (LCWS 2023) at the SLAC National Accelerator Laboratory. Together with colleagues from around the world, the linear collider community hereby issues the following statement:

1. Particle physics needs a new accelerator to measure the properties of the Higgs boson with high precision.

The Higgs boson is central to our understanding of the evolution of the Universe. It plays a critical role in all of the interactions studied in particle physics, and in the mysteries whose solution is central to progress in this field. Of all ways to search for physics beyond the Standard Model, precision measurements on the Higgs boson access the widest variety of new physics interactions. The "strong scientific importance" of precision Higgs measurements was emphasized in the 2014 P5 report in the US. The need for an e^+e^- Higgs factory as the next collider was called for in the 2020 update of the European Strategy for Particle Physics and in the Energy Frontier report from Snowmass 2021.

2. The particle physics community needs to realize the e^+e^- Higgs factory as soon as possible.

Data-taking at a future e^+e^- Higgs factory should follow the HL-LHC directly, requiring construction start by 2030, in parallel with HL-LHC data-taking. This will ensure that essential and unique expertise and human resources will remain available. A long delay will dissipate these resources and endanger the future of our field.

We recommend that the e^+e^- Higgs factory should be based on a linear collider. There are many advantages of the linear approach. Among these, linear colliders are able to access energies of 500 GeV and beyond. This will allow measurements that must be included in the search for new physics through precision, including measurement of the top quark mass and electroweak couplings, the top quark Higgs coupling, and the cross section for double Higgs production. Proposed linear collider Higgs factories are designed for greater compactness, energy efficiency, and sustainability, with correspondingly lowered construction and operation costs.

3. The realization of the Higgs factory requires immediate funding for both accelerator and detector R&D.

Operation of an e^+e^- Higgs factory on this timeline requires both accelerator and detector R&D on the scale needed to produce engineering designs. There are new developments in the ILC technology, leading to performance improvements and cost reductions. Further advances in ILC technology, as well as alternative technologies such as C^3 and CLIC, promise lower costs and/or extended energy reach for later stages of this program. These developments need to be evaluated rigorously with dedicated R&D. Precision measurements of the Higgs boson and other heavy particles are challenging. The requirements call for a dedicated detector R&D program, bringing new ideas from the LHC and elsewhere to achieve the goal of measurements of ultimate precision. The new ILC Technology Network is an important first step toward this goal, but more is needed. The Higgs factory program needs to begin now.

4. The Higgs factory needs a definite plan for funding and construction.

We support the construction of the ILC in Japan as the most direct route to the Higgs factory physics program. At the same time, we are investigating other possible sites and technologies, for example, hosting by the US as suggested by the Snowmass Energy Frontier report, or in Europe. Whatever the site, the e^+e^- Higgs factory will need to be constructed as a global facility. We need to build the funding and governance agreements that will make this possible.

5. The e^+e^- Higgs factory is the bridge to our high-energy future.

For the future of particle physics, we look forward to exploring higher energies, with quark and lepton collisions at 10 times the energies of the LHC. New technologies are proposed, using pp, muon, and e^+e^- colliders. All of these will require decades of R&D. Construction and operation of a linear Higgs factory will contribute to this R&D, developing accelerator science, keeping all of these options open, and providing challenges to train young scientists. The new results will be relevant to all approaches for reaching higher energies and luminosities, and for applications beyond particle physics. Discoveries at a Higgs factory may point to specific goals for higher energy machines. The Higgs factory will serve as a bridge from the LHC to the future of high energy physics research.

6. We are committed to carrying out the precision Higgs measurements, which we consider the leading path toward further progress in particle physics.

https://indico.slac.stanford.edu/event/7467/page/61-statement-to-p5

My Conclusions

My Conclusions

LCWS 2023 was an interesting and vibrant meeting

- Bringing the community together in person for the first time since Sendai 2019
- Steady progress in machine and detector R&D presented

Re-focusing to a broader scope of possible technologies and sites vitalised the scientific programme

- ILC in Japan is in an increasingly unclear situation
- Time lines for the realisation of any Higgs Factory are getting more uncertain
- New proposals like C^3 and HALHF are fruitful ingredients for the discussions on the future of our field

PWA has best chances to become the next disruptive technology for HEP colliders

Sustainability has to be taken into account from the beginning

- Operation is only half of the account, construction needs to be folded in

The big ring proposals (FCC, CEPC) are … big

The future is probably linear